

# COVID-19 Modelling

PHAC Agent-based Model:  
User Notes for Version 48

## Overview of steps to modify and run the model

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# 1 Introduction to the PHAC agent-based model

The PHAC agent-based model has been developed to simulate the potential spread of SARS-CoV-2 in the Canadian population. The model is parameterised using scientific information of SARS-CoV-2 from the literature with a Canadian context in mind (i.e. Canadian demographic structure, Canadian contact matrices projections, Canadian epidemiological data, etc.). Stochasticity in the model allows for a range of outputs that provide an estimate of the most likely values with lower and upper bounds.

This guide is intended to provide users with information on how to 1) download and run the model, 2) tailor the model to specific communities, 3) run scenarios testing non-pharmaceutical interventions, and 4) navigate the model outputs.

## 2 Download required software

The model is developed in AnyLogic, which is a Java-based simulation tool that supports multiple types of mathematical and simulation modelling. The structure of AnyLogic is based on stock-and-flow diagrams and object-oriented language that governs how agents within specific environments will behave. A free version of AnyLogic (the Personal Learning Edition) can be downloaded [here](#).

The model runs using a code-based experiment called the "Custom Experiment." In order to run the full sized model using the Custom Experiment, you will need to download a 30-day evaluation trial of AnyLogic Professional, as the Custom Experiment will not run on the Personal Learning Edition. Single simulation runs can still be executed in the Personal Learning Edition.

## 3 Modify parameters in the Inputs.xlsx spreadsheet

The model is continuously being updated and modified over time. The most notable difference between earlier versions of the model (e.g. version 45, which is the version published in [Ng et al. 2020](#)) and more recent versions is the added feature to modify parameters in an Excel spreadsheet titled Inputs.xlsx. In earlier versions, the parameters were modified directly in AnyLogic by writing code to specify their input values. For the purposes of this guide, the instructions will focus on how to modify parameters for later versions of the model (versions 48 and higher) using the Excel spreadsheet. To modify earlier versions of the model, and for instructions on how to customize parameters beyond the Excel spreadsheet, please refer to "**5 Final modifications using the CustomExperiment**" (page 15).

### 3.1 Initial model set-up (tab: SimulationParameters)

The initial model set-up includes specifying global parameters that dictate how the model will run. These parameters can be modified by going to the SimulationParameters tab in the Inputs spreadsheet.

Parameter	Description	Example input
<b>NumberOfThreads</b>	Number of simultaneous runs to execute (depends on the machine's CPU)	4
<b>NumberOfReplications</b>	Number of replications to be run	50
<b>ModelDuration</b>	Model duration, in days*	700

\*The model start date is set to February 7, 2020

## 3.2 Age structure (tab: AgeGroup)

The model is age-structured, which means that several parameters and outcomes are specific to the defined age groups. The age distribution currently used in the model is parameterized based on estimates from the national Canadian population. The distribution can be modified through the following steps:

1. Define the proportion of the population in each age category (outlined in the table below). The proportion can be calculated by dividing the number of individuals in each age category by the total population size.
2. The age distribution can be calculated by dividing the proportion by the number of ages included in each category. For example, if 5% of the population are between the ages of 0 and 4, the input parameter would be calculated as  $0.05/5$ . The resulting value (0.01) would be entered as the parameter value for that age category.
3. The age distribution can be modified in the AgeGroup tab of the Inputs spreadsheet.

Parameter	Age group (in years)	Example age distribution input*
<b>ag_Child1</b>	0 to 4	0.01033899
<b>ag_Child2</b>	5 to 9	0.010850716
<b>ag_Child3</b>	10 to 14	0.010810332
<b>ag_Youth</b>	15 to 19	0.011251272
<b>ag_Adult1</b>	20 to 44	0.013522096
<b>ag_Adult2</b>	45 to 54	0.013033172
<b>ag_Adult3</b>	55 to 64	0.013997386
<b>ag_Senior1</b>	65 to 74	0.010118227
<b>ag_Senior2</b>	75 to 84	0.005190262
<b>ag_Elderly</b>	≥85	0.001486706

\*These values correspond to the age distribution based on estimates from the national Canadian population, note that these values do not add up to 1 as they represent age distribution rather than proportion of the population.

### 3.3 Household structure (tab: ParametersValues)

There are two options to specify household structure in the model. Option 1 defines the total number of households, with members assigned based on minimum and maximum household sizes. Option 2 defines the number of households according to the specific household size, which will, in general, lead to more accurate modelling results. When modelling smaller populations, the use of specified household sizes (Option 2) is important to accurately represent the population structure and project transmission dynamics.

#### 3.3.1 Option 1 (estimated household sizes)

To use estimated household sizes, go to the **ParametersValues** tab in the **Inputs** spreadsheet and change **FixedHouseholdCount\_0no\_1yes** to **0**. Enter the input data for the parameters in the table below. The attribution of each household will be done using a uniform distribution across all household sizes.

Parameter	Description	Example input
<b>TotalHouseholds</b>	Total number of households	100
<b>MaxHouseholdSize</b>	Maximum household size	5
<b>MinHouseholdSize</b>	Minimum household size	1

#### 3.3.2 Option 2 (specified household sizes)

To use specified household sizes, go to the **ParametersValues** tab in the **Inputs** spreadsheet and change **FixedHouseholdCount\_0no\_1yes** to **1**. Enter the input data for the parameters in the table below.

Parameter	Description	Example input*
<b>NbrHouseholdSize1</b>	# of 1-member households	11725
<b>NbrHouseholdSize2</b>	# of 2-member households	13900
<b>NbrHouseholdSize3</b>	# of 3-member households	6200
<b>NbrHouseholdSize4</b>	# of 4-member households	5800
<b>NbrHouseholdSize5</b>	# of 5-member households	2500
<b>NbrHouseholdSize6</b>	# of 6-member households	750
<b>NbrHouseholdSize7</b>	# of 7-member households	125
<b>NbrHouseholdSize8</b>	# of 8-member households	100
<b>NbrHouseholdSize9</b>	# of 9-member households	0
<b>NbrHouseholdSize10</b>	# of 10-member households	0
<b>NbrHouseholdSize11</b>	# of 11-member households	0
<b>NbrHouseholdSize12</b>	# of 12-member households	0

\*Based on a population size of 100,000 agents

## 3.4 Community structure (tabs: ParametersValues, OutsideDistribution)

There are two options to specify community structure in the model. Option 1 defines the total number of common spaces and assigns type (i.e. school, workplace, or mixed-age venue) based on a distribution. Option 2 specifies the exact number of schools, workplaces, and mixed-age venues in a community which will, in general, lead to more accurate modelling results.

### 3.4.1 Option 1 (using total number of common spaces)

To define a total number of common spaces, go to the **ParametersValues** tab in the **Inputs** spreadsheet and change **FixedOutsidePlacesCount\_0no\_1yes** to **0**. Enter the input data for **TotalCommonSpaces**.

Parameter	Description	Example input
<b>TotalCommonSpaces</b>	Total number of common spaces (schools, workplaces and mixed-age venues) in the community	30

Then, go to the **OutsideDistribution** tab and enter the input data for **Schools**, **Workplaces**, and **MixedAgeVenues**. Note that the proportion of schools, workplaces and mixed-age venues must add up to 100%, i.e. 1 (for e.g. in this example  $0.05 + 0.5 + 0.45$ ). The defined proportions are used as probability distributions in the model. For example, the values will not always result in exactly 15 workplaces (there will be a slight variation between model runs).

Parameter	Description	Example input
<b>Schools</b>	Proportion of schools in the community	0.05
<b>Workplaces</b>	Proportion of workplaces in the community	0.5
<b>MixedAgeVenues</b>	Proportion of mixed-age venues in the community	0.45

### 3.4.2 Option 2 (using exact number of schools, workplaces, and mixed-age venues)

To use the exact number of each type of common space, go to the **ParametersValues** tab in the **Inputs** spreadsheet and change **FixedOutsidePlacesCount\_0no\_1yes** to **1**. Enter the input data for the parameters in the table below.

Parameter	Description	Example input
<b>NbrSchools</b>	Number of schools in the community	40
<b>NbrWorkplaces</b>	Number of workplaces in the community	750
<b>NbrMixedAgeVenues</b>	Number of mixed-age venues in the community	415

## 3.5 Healthcare infrastructure (tab: ParametersValues)

Healthcare infrastructure parameters can be modified by going to the **ParameterValues** tab in the **Inputs** spreadsheet. Note that the number of hospital beds available should reflect the number that are available for the population you are modelling. If you are modelling per 100,000, then this needs to be modified accordingly.

Parameter	Description	Example input
HospitalizationThreshold	Number of hospital beds available	30
ICUThreshold	Number of ICU beds available	9
ICU_mode_1Rural_0Urban	Control ICU overcapacity settings for rural or urban areas (if rural area, assumes that ICU patients will be exported to nearest large city)	0

### 3.6 Initial infections (tabs: Infect\_Existing\_People, Insert\_Infected\_People)

There are two ways that individuals can be manually infected in the model: 1) existing individuals can be infected (initial cases that propagate local transmission), or 2) new individuals can be infected (representative of imported cases). Currently, the model is parameterized to have both occur simultaneously. That is, new infections come from both existing individuals at the start of the model run, followed by the import of infected individuals as time progresses. To only have one option occur, the corresponding rows in the Excel file can be deleted.

#### 3.6.1 Specifying initial cases

1. In the ParameterValues tab of the Inputs spreadsheet, specify the initial number of infected cases in the InitialInfected parameter field.
2. Go to the Infect\_Existing\_People tab. This table specifies descriptive information about the initial cases, such as the date they should be infected (in model time, starting at day 0) and their age (specified as minimum and maximum values). If you want an individual of a specific age, you can make the minimum and maximum values the same, however, when modelling a small population, by chance an individual of a specific age may not exist, so it is better to specify a range when initialising a model with initially infected individuals, especially when modelling a very small population. Each initial case should have a corresponding line in the table (e.g. for six initial cases, there should be six lines with descriptive information on the case). See the aside table as an example.

Day	Min Age	Max Age
0	45	55
3	0	20
6	65	75
9	55	65
12	65	75
15	45	55

#### 3.6.2 Specifying imported cases

1. The Insert\_Infected\_People tab of the Inputs spreadsheet has a table of descriptive information about imported cases that will be inserted as the model is running.
2. The descriptive information includes the day they should be inserted (in model time, starting at day 0), how long they should stay in the model (in model time), the number of people that should be inserted at that time point, the age of the infected person, and the common space where they should be added (workplace, school, or mixed age venue). Note that imported cases enter the population in the Exposed state. By default they are not infectious until they have passed their latent period (currently defined by a distribution with a mean of 3.77 days).
3. This table can be modified to include any number of imported cases.

Day	Duration of stay	Number of people	Age	CommonSpace
23	700	1	18	Workplace
30	700	1	7	School
37	700	1	89	Mixed
44	700	1	45	Workplace
51	700	1	15	School
58	700	1	40	Mixed

### 3.7 Additional population parameters (tabs: ContactMatrix, AgeGroupsOutsidePlaces)

Several other parameters can be modified to tailor the model to specific communities, given that data are available. These include: 1) the contact matrix, which specifies how individuals in different age groups contact each other (in the **ContactMatrix** tab); 2) the distribution of agents by age into common mixing environments during weekdays (in the **AgeGroupsOutsidePlaces** tab); 3) probability of movement outside of the home on weekdays and weekends for each age group (in the **ParametersAgeGroup** tab, controlled by the parameters following the pattern **p\_ProportionChild1WhoLeaveOnWeekdays**, **p\_ProportionChild2WhoLeaveOnWeekdays**, etc).

### 3.8 Health and hospitalization states (tabs: ParametersAgeGroups, ParametersExpressions)

The model contains a framework of compartments representing epidemiological health states of agents (please see Ng et al. 2020 for full details). All agents begin as susceptible except for infected agents used to seed transmission. Infection occurs on successful contact between susceptible and infectious agents. Infectious agents occur as four states: asymptomatic, pre-symptomatic, mild symptomatic and severe symptomatic. We assumed severe cases, after a pre-symptomatic period, will remain at home until hospitalization and only transmit infection to household members at a reduced rate of 50%. In contrast, asymptomatic, pre-symptomatic and mild cases can infect both at home and in common environments. On infection, agents progress through different health states beginning with the exposed states (distinguished by those exposed by a symptomatic case and those exposed by an asymptomatic case) until either recovery or death is reached. We assumed recovered individuals remain immune from re-infection for the duration of the model run. The duration in which agents remain in each epidemiological health state varied between agents and was determined by sampling from probability distributions defined by the literature or Canadian data.

The parameters used in the model were based on literature estimates from June 2020, so their values will need to be revised as new information about SARS-CoV-2 becomes available. The values used, and instructions on how to modify them, are provided in the tables below.

The following parameters can be modified in the **ParametersExpressions** tab of the **Inputs** spreadsheet:

Parameter	Description	Value
<b>LatentPeriod</b>	Latent period (days)	pert(2, 5, 3.77)
<b>PreInfectiousPeriod</b>	Pre-symptomatic infectious period (days)	pert(1, 3, 2.5)

<b>A_InfectiousPeriod</b>	Asymptomatic infectious period (days)	pert(3.5, 10, 6)
<b>MildInfectiousPeriod</b>	Mild infectious period (days)	pert(3, 7, 3.5)
<b>MildIllnessDuration</b>	Remaining duration of mild illness (days)	pert(2, 5, 3)
<b>TimeToHospitalization</b>	Time to hospitalization period (days)	normal(0.5, 5)
<b>HospitalizationPeriod</b>	Hospitalization period (days)	pert(3, 14, 10)
<b>HospitalizationToICUPeriod</b>	Hospitalization to ICU period (days)	normal(0.3, 3)
<b>ICUPeriod</b>	ICU period (days)	pert(4, 13, 8)
<b>PostICURecoveryPeriod</b>	Post-ICU hospitalization period (days)	pert(3, 10, 7)

The following parameters can be modified in the **ParametersAgeGroups** tab of the **Inputs** spreadsheet:

<b>Parameter</b>	<b>Description</b>	<b>Value</b>
<b>InfectionProbabilityChild1</b>	Transmission probability ( $\beta$ ) (aged 0-4)	0.03931058
<b>InfectionProbabilityChild2</b>	Transmission probability ( $\beta$ ) (aged 5-9)	0.03931058
<b>InfectionProbabilityChild3</b>	Transmission probability ( $\beta$ ) (aged 10-14)	0.03931058
<b>InfectionProbabilityYouth</b>	Transmission probability ( $\beta$ ) (aged 15-19)	0.03931058
<b>InfectionProbabilityAdult1</b>	Transmission probability ( $\beta$ ) (aged 20-44)	0.03931058
<b>InfectionProbabilityAdult2</b>	Transmission probability ( $\beta$ ) (aged 45-54)	0.03931058
<b>InfectionProbabilityAdult3</b>	Transmission probability ( $\beta$ ) (aged 55-64)	0.03931058
<b>InfectionProbabilitySenior1</b>	Transmission probability ( $\beta$ ) (aged 65-74)	0.03931058
<b>InfectionProbabilitySenior2</b>	Transmission probability ( $\beta$ ) (aged 75-84)	0.03931058
<b>InfectionProbabilityElderly</b>	Transmission probability ( $\beta$ ) (aged 85+)	0.03931058
<b>ContactsPerDayChild1Weekday</b>	Age-specific contact rate (aged 0-4)	9.0957
<b>ContactsPerDayChild2Weekday</b>	Age-specific contact rate (aged 5-9)	10.5341
<b>ContactsPerDayChild3Weekday</b>	Age-specific contact rate (aged 10-14)	13.0621
<b>ContactsPerDayYouthWeekday</b>	Age-specific contact rate (aged 15-19)	20.3667
<b>ContactsPerDayAdult1Weekday</b>	Age-specific contact rate (aged 20-44)	15.3519
<b>ContactsPerDayAdult2Weekday</b>	Age-specific contact rate (aged 45-54)	14.9039
<b>ContactsPerDayAdult3Weekday</b>	Age-specific contact rate (aged 55-64)	11.0106
<b>ContactsPerDaySenior1Weekday</b>	Age-specific contact rate (aged 65-74)	6.5229
<b>ContactsPerDaySenior2Weekday</b>	Age-specific contact rate (aged 75-84)	4.5929
<b>ContactsPerDayElderlyWeekday</b>	Age-specific contact rate (aged 85+)	4.5929
<b>ProportionSymptomaticChild1</b>	Probability of symptomatic infection (aged 0-4)	0.5
<b>ProportionSymptomaticChild2</b>	Probability of symptomatic infection (aged 5-9)	0.5
<b>ProportionSymptomaticChild3</b>	Probability of symptomatic infection (aged 10-14)	0.5
<b>ProportionSymptomaticYouth</b>	Probability of symptomatic infection (aged 15-19)	0.5
<b>ProportionSymptomaticAdult1</b>	Probability of symptomatic infection (aged 20-44)	0.6
<b>ProportionSymptomaticAdult2</b>	Probability of symptomatic infection (aged 45-54)	0.7
<b>ProportionSymptomaticAdult3</b>	Probability of symptomatic infection (aged 55-64)	0.7



Parameter	Description	Value
<b>ProportionSymptomaticSenior1</b>	Probability of symptomatic infection (aged 65-74)	0.8
<b>ProportionSymptomaticSenior2</b>	Probability of symptomatic infection (aged 75-84)	0.95
<b>ProportionSymptomaticElderly</b>	Probability of symptomatic infection (aged 85+)	10
<b>HospitalizationChild1</b>	Hospitalization proportion (aged 0-4)	0.03671
<b>HospitalizationChild2</b>	Hospitalization proportion (aged 5-9)	0.00818
<b>HospitalizationChild3</b>	Hospitalization proportion (aged 10-14)	0.01668
<b>HospitalizationYouth</b>	Hospitalization proportion (aged 15-19)	0.02658
<b>HospitalizationAdult1</b>	Hospitalization proportion (aged 20-44)	0.05348
<b>HospitalizationAdult2</b>	Hospitalization proportion (aged 45-54)	0.11904
<b>HospitalizationAdult3</b>	Hospitalization proportion (aged 55-64)	0.21184
<b>HospitalizationSenior1</b>	Hospitalization proportion (aged 65-74)	0.40341
<b>HospitalizationSenior2</b>	Hospitalization proportion (aged 75-84)	0.52133
<b>HospitalizationElderly</b>	Hospitalization proportion (aged 85+)	0.44169
<b>ICUChild1</b>	ICU admission (aged 0-4)	0.17241
<b>ICUChild2</b>	ICU admission (aged 5-9)	0.0
<b>ICUChild3</b>	ICU admission (aged 10-14)	0.29412
<b>ICUYouth</b>	ICU admission (aged 15-19)	0.20513
<b>ICUAdult1</b>	ICU admission (aged 20-44)	0.22644
<b>ICUAdult2</b>	ICU admission (aged 45-54)	0.28866
<b>ICUAdult3</b>	ICU admission (aged 55-64)	0.30579
<b>ICUSenior1</b>	ICU admission (aged 65-74)	0.28292
<b>ICUSenior2</b>	ICU admission (aged 75-84)	0.15492
<b>ICUElderly</b>	ICU admission (aged 85+)	0.04819
<b>DeathHospChild1</b>	Mortality rate from general hospital admissions (aged 0-4)	0.0
<b>DeathHospChild2</b>	Mortality rate from general hospital admissions (aged 5-9)	0.0
<b>DeathHospChild3</b>	Mortality rate from general hospital admissions (10-14)	0.0
<b>DeathHospYouth</b>	Mortality rate from general hospital admissions (15-19)	0.0
<b>DeathHospAdult1</b>	Mortality rate from general hospital admissions (20-44)	0.0088
<b>DeathHospAdult2</b>	Mortality rate from general hospital admissions (44-54)	0.0188
<b>DeathHospAdult3</b>	Mortality rate from general hospital admissions (55-64)	0.0758
<b>DeathHospSenior1</b>	Mortality rate from general hospital admissions (65-74)	0.2252
<b>DeathHospSenior2</b>	Mortality rate from general hospital admissions (75-84)	0.352
<b>DeathHospElderly</b>	Mortality rate from general hospital admissions (85+)	0.4719
<b>DeathICUChild1</b>	Mortality rate from ICU admissions (aged 0-4)	0.0
<b>DeathICUChild2</b>	Mortality rate from ICU admissions (aged 5-9)	0.0
<b>DeathICUChild3</b>	Mortality rate from ICU admissions (aged 10-14)	0.0

Parameter	Description	Value
DeathICUYouth	Mortality rate from ICU admissions (aged 15-19)	0.0
DeathICUAdult1	Mortality rate from ICU admissions (aged 20-44)	0.0927
DeathICUAdult2	Mortality rate from ICU admissions (aged 45-54)	0.1559
DeathICUAdult3	Mortality rate from ICU admissions (aged 55-64)	0.2432
DeathICUSenior1	Mortality rate from ICU admissions (aged 65-74)	0.3555
DeathICUSenior2	Mortality rate from ICU admissions (aged 75-84)	0.5294
DeathICUElderly	Mortality rate from ICU admissions (aged 85+)	0.7294
OvercapacityRate	Impact to mortality rate when hospital and ICU beds are overcapacity (e.g. mortality rate doubles)	2

### 3.9 Non-pharmaceutical interventions (tab: ParametersAgeGroup)

The model explored 4 interventions (case detection and isolation, contact tracing and quarantine, personal physical distancing to reduce the daily contact rate, and community closure) individually and together. A description of the interventions are contained in the table below.

Intervention type	Impact	Model component
<b>Case detection &amp; isolation</b>	Case testing to identify symptomatic cases resulting in isolation of these individuals in their household, thereby reducing community transmission. Agents that are identified via case testing are isolated at home for 14 days. In addition, a proportion of household members also isolate unless they have been previously infected and are immune. For this intervention, isolation compliance (i.e. IsolationComplianceChild1, IsolationComplianceChild2, etc) is set to 1 for all age groups indicating that all symptomatic cases that are detected will comply to isolation. Note by the time agents arrive in the mildly symptomatic state, they have already been infectious for 1 to 3 days, but isolating them in this state will prevent a further 3 to 7 days of potential community transmission. Isolated agents can continue to infect household members, but at a reduced contact rate of 50% as we assume sick individuals will impose some form of physical distancing in the household.	Mild symptoms
<b>Contact tracing &amp; quarantine</b>	Contact tracing to identify individuals who have been exposed and infected but are not yet infectious. This intervention is one of the most effective because an agent who is quarantined for 14 days in the exposed state will not be a source of community infection at any point during their infection. For this intervention, compliance is set to 1 for all age groups indicating that all agents traced will comply with quarantine.	Exposed

Intervention type	Impact	Model component
<b>Physical distancing</b>	Reduce the number of contacts per day; can be applied to the entire population or targeted by age group. Physical distancing was applied only outside the household. For this intervention, compliance is set to 1 for all age groups indicating that all individuals will adhere to physical distancing.	All agent states
<b>Community closure</b>	Closure of schools, workplaces and mixed-age venues either as a proportion (e.g. 100% of schools) or as a threshold (e.g. workplaces with 50 or more assigned agents). Agents who are assigned to a community environment that is closed are forced to stay at home until closure has ended.	N/A

### 3.9.1 Baseline interventions

The first 94 days in the model represents the Canadian baseline (February 7 to May 10, 2020). This is the period in which we initially observe community transmission in Canada and case detection, isolation and contact tracing is applied from the onset. By mid-March (March 16, 2020), heavy restrictions are put in place with the closure of schools and non-essential businesses in many provinces and territories. In the baseline scenario, these closures are lifted on May 11, 2020. To configure the non-pharmaceutical interventions in the baseline time period, ensure that the following parameters are set according to the table below. The parameters can be modified in the ParametersAgeGroup tab of the Inputs spreadsheet.

Intervention	Description	Parameter	Input
<b>Case detection &amp; isolation</b>	20% of symptomatic cases are detected and isolated for their remaining infectious period (50% of their household members also co-isolate).	IsolationStartDay	0
		DurationIsolation	14
		GlobalDurationIsolation	700*
		CaseTesting	0.2
		IsolationFamilyCompliance	0.5
		IsolationComplianceChild1 (etc <sup>+</sup> )	1
<b>Contact tracing &amp; quarantine</b>	Of the 20% of cases that are detected, 50% are traced and quarantined.	ContactTracingStartDay	0
		DurationQuarantine	14
		GlobalDurationQuarantine	700*
		ContactTracing	0.1
		QuarantineComplianceChild1 (etc <sup>+</sup> )	1
<b>Physical distancing</b>	20% reduction in personal contact rate outside of the home.	DurationSocialDistancing	700*
		SocialDistancingStartDay	38 <sup>±</sup>
		Phase1Reduction <sup>^</sup>	0.8
		SocialDistancingComplianceChild1 (etc <sup>+</sup> )	1

Intervention	Description	Parameter	Input
<b>Community closures</b>	100% of schools, 40% of workplaces and 50% of mixed age meeting venues are closed for a duration of 8 weeks.	ClosureStartDay	38 <sup>±</sup>
		DurationClosure	56
		ProportionClosedSchools	1
		ProportionClosedWorkplaces	0.4
		ProportionClosedMixedAgeVenues	0.5

\*Set value to model duration (in days)

+Parameters follow the age group pattern: Child1, Child2, Child3, Youth, Adult1, etc

±Model day 38 corresponds to March 16, 2020, when additional restrictive measures were implemented

^There are four phases of physical distancing that can be explored in the model, for each phase there is a corresponding PhaseXStart to indicate the start of the next phase. These can be left untriggered for the entire model run by setting the start date to a day that is beyond the model run duration, i.e. 9999 for a 700-day model run.

### 3.9.2 Implementing public health scenarios

The public health scenarios are constructed by building on, and combining, the four interventions listed above. The following table describes the combination of parameter values used to replicate the scenarios in Ng et al. (2020). Each scenario is set to begin after the baseline period of restrictive closures, which corresponds to May 11, 2020 (model day 94). Additional scenarios can be created by modifying or combining the parameters that control each of the intervention.

#### 3.9.2.1 Scenario 1: Minimal control

Intervention	Description	Parameter	Input
<b>Case detection &amp; isolation</b>	20% of symptomatic cases are detected and isolated for their remaining infectious period (50% of their household members also co-isolate). This level of case detection and isolation is maintained for the duration of the model run.	IsolationStartDay	0
		DurationIsolation	14
		GlobalDurationIsolation	700 <sup>*</sup>
		CaseTesting	0.2
		IsolationFamilyCompliance	0.5
		IsolationComplianceChild1 (etc <sup>+</sup> )	1
		EnhanceIsolationStartDay	9999 <sup>±</sup>
<b>Contact tracing &amp; quarantine</b>	20% of cases are detected, and of these, 50% of their contacts are traced and quarantine. This level of contact tracing and quarantine is maintained for the duration of the model run.	ContactTracingStartDay	0
		DurationQuarantine	14
		GlobalDurationQuarantine	700 <sup>*</sup>
		ContactTracing	0.1
		QuarantineComplianceChild1 (etc <sup>+</sup> )	1
		EnhanceQuarantineStartDay	9999 <sup>±</sup>

Intervention	Description	Parameter	Input
<b>Physical distancing</b>	20% reduction in personal contact rate outside of the home from day 38 to 93.	DurationSocialDistancing	700*
		SocialDistancingStartDay	38
		Phase1Reduction	0.8
		Phase2Start	94
		SocialDistancingComplianceChild1 (etc <sup>+</sup> )	1
		Phase2Reduction	1
<b>Community closures</b>	Community closure occurs from day 38 to 93 with no further closures.	ClosureStartDay	38
		DurationClosure	56
		ProportionClosedSchools	1
		ProportionClosedWorkplaces	0.4
		ProportionClosedMixedAgeVenues	0.5

\*Set value to model duration (in days)

+Parameters follow the age group pattern: Child1, Child2, Child3, Youth, Adult1, etc

±Setting value to 9999 ensures the enhanced interventions do not turn on during the scenario

### 3.9.2.2 Scenario 2: Maintained physical distancing

Intervention	Changes from Scenario 1	Parameters affected	New input
<b>Case detection &amp; isolation</b>	No change	—	—
<b>Contact tracing &amp; quarantine</b>	No change	—	—
<b>Physical distancing</b>	Physical distancing is maintained after closures are lifted, resulting in a 20% reduction in contact rate for the model duration	Phase2Start	94
		Phase2Reduction	0.8
<b>Community closures</b>	No change	—	—

### 3.9.2.3 Scenario 3: Enhanced case detection and contact tracing

Intervention	Changes from Scenario 1	Parameters affected	New input
<b>Case detection &amp; isolation</b>	Case detection is enhanced after closures are lifted, resulting in 50% of symptomatic cases detected and isolated for their remaining infectious period	EnhanceIsolation	0.5
		EnhanceIsolationStartDay	94
<b>Contact tracing &amp; quarantine</b>	Contact tracing is enhanced after closures are lifted. 50% of cases are detected, and of these, 100% of the contacts are traced and quarantine	EnhanceContactTracing	0.5
		EnhanceQuarantineStartDay	94

Intervention	Changes from Scenario 1	Parameters affected	New input
Physical distancing	No change	—	—
Community closures	No change	—	—

### 3.9.2.4 Scenario 4: Combined interventions

Intervention	Changes from Scenario 1	Parameters affected	New input
Case detection & isolation	Case detection is enhanced after closures are lifted, resulting in 50% of symptomatic cases detected and isolated for their remaining infectious period	EnhanceIsolation	0.5
		EnhanceIsolationStartDay	94
Contact tracing & quarantine	Contact tracing is enhanced after closures are lifted. 50% of cases are detected, and of these, 100% of the contacts are traced and quarantine	EnhanceContactTracing	0.5
		EnhanceQuarantineStartDay	94
Physical distancing	Physical distancing is maintained after closures are lifted, resulting in a 20% reduction in contact rate for the model duration	Phase2Start	94
		Phase2Reduction	0.8
Community closures	No change	—	—

### 3.9.3 Implementing additional interventions

Interventions added to the model after the publication of Ng et al. (2020) are provided in the table below.

Intervention	Impact	Parameter	Input
Community testing	Additional testing to identify agents who are exposed by an unknown source (i.e. asymptomatic agents who are out in the community causing infection). Note that community testing can also be enhanced by changing the corresponding enhanced parameters	CommunityTestingStartDay	0
		EnhanceCommunityTestingStartDay	9999 <sup>±</sup>
		CommunityTesting	0.4
		EnhanceCommunityTesting	0.4

<sup>±</sup>Setting value to 9999 ensures the enhanced interventions do not turn on during the scenario, this can be changed to trigger the enhancement

## 4 Update the model with new parameters

After the parameter values are updated in the Excel spreadsheet, they need to be linked to the model file in AnyLogic. To do this, open the model (**File > Open**). In the left navigation menu, click on Database, which will load several options in the right navigation menu. Click on **Update tables data** in the right menu. To verify that the parameters were correctly updated, double-click on **Database** in the left menu. Double-clicking on any of the nested tables in the **Database** menu will open the parameters with their updated values.

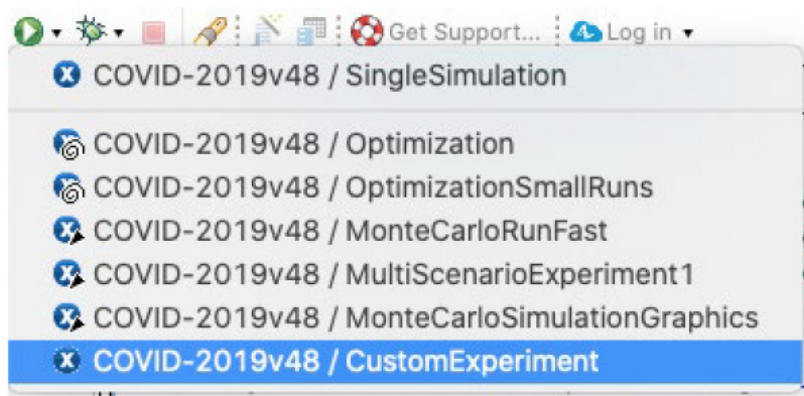
## 5 Final modifications using the CustomExperiment

The **CustomExperiment** contains the code that executes the model. This code can be viewed and modified by double clicking on **CustomExperimentMainClass** in the left navigation menu. All of the parameters included in the **Inputs** spreadsheet can be modified directly in the code for the **CustomExperiment**. For earlier model versions without the **Inputs** spreadsheet (version 47 and below), all of the parameters listed in the above sections can be modified by specifying the input values in the **CustomExperiment** code. For model versions that use the **Inputs** spreadsheet, parameters can be modified using both the spreadsheet and the **CustomExperiment** code, taking note that any parameter values specified in the **CustomExperiment** will override those in the **Inputs** spreadsheet.

In the **CustomExperiment** code, parameter values can be entered after line 16. Parameter values can be specified by typing the parameter name with the **root.** prefix. For example, **root.TotalHouseholds = 2000** (to specify the number for the parameter **TotalHouseholds** in the Main agent should equal to 2000); **root.TotalCommonSpaces = 200** (to specify the number for the parameter **TotalCommonSpaces** in the Main agent should equal to 200) ; etc.

## 6 Final modifications using the CustomExperiment

To run the model, navigate to the top menu bar. Click on the drop-down list next to the green arrow button (pictured below, in the top left corner) and select **CustomExperiment**.



## 7 Summarize model results

Several .csv files are saved in the model folder after a model run. Each file contains daily outputs for the entire simulation, with each iteration appended under the next. It is important to note that each new model run (e.g. running the model after configuring the parameters) will result in the output files overwriting any existing .csv files that are contained in the model folder, so they need to be moved to a separate location if the results from several scenarios need to be saved in one location.

### 7.1 Description of output .csv files

The model contains several health states, including: **Susceptible**, **UExposed** (exposed individuals from asymptomatic infections), **Exposed** (exposed individuals from symptomatic infections), **A\_Infectious** (asymptomatic infections), **Infectious**, **MildSymptoms** (infectious stage), **MildSymptoms2** (no longer infectious but still symptomatic), **SevereSymptoms**, **Hospitalized**, **PreICUHosp**, **ICU**, **PostICUHosp**, **A\_Recovered** (asymptomatic recovered), **S\_Recovered** (symptomatic recovered) and **Removed** (deaths).

For each health state, there are two types of output files:

1. Files beginning with the title **Cum\_** indicates cumulative counts over time, i.e. **Cum\_AInfectious** contains cumulative counts over time for the **AInfectious** health state
2. Files without the title **Cum\_** indicates prevalent counts over time, i.e. **AInfectious** contains prevalent counts over time for the **AInfectious** health state

Furthermore, .csv output files are organised into age groups as well as summed over all ages. Age specific files are labelled as follows: **Child1** (0 to 4 years), **Child2** (5 to 9 years), **Child3** (10 to 14 years), **Youth** (15 to 19 years), **Adult1** (20 to 44 years), **Adult2** (45 to 54 years), **Adult3** (55 to 64 years), **Senior1** (65 to 74 years), **Senior2** (75 to 84 years), and **Elderly** (85 years and older). For example, **Cum\_AInfectious** contains the cumulative case count data for the **AInfectious** state for all age groups while **CumAInfectious\_Child1** contains the cumulative case count data for the **AInfectious** state for those between the ages of 0 and 4.

There is also one summary metric file called **Final\_Metrics\_AllRuns.csv**, which contains a summary of the model iterations. The variable list is included in the table below.

Variable	Description
<b>ClinicalAttackRate</b>	Clinical attack rate (proportion of the population that were clinically ill)
<b>TotalAttackRate</b>	Total attack rate (proportion of the population that were infected, including asymptomatic cases)
<b>MortalityRate</b>	Proportion of deaths of all the symptomatic cases (there are no deaths from asymptomatic cases). This is the case fatality rate.
<b>HospMortalityRate</b>	Proportion of deaths from hospitalized cases
<b>ICUMortalityRate</b>	Proportion of deaths from ICU admitted cases
<b>ProportionMild</b>	Proportion of all clinical cases that are mild



<b>Variable</b>	<b>Description</b>
<b>ProportionHospitalized</b>	Proportion of all clinical cases that are hospitalized
<b>ProportionICU</b>	Proportion of all hospitalized cases that move into the ICU
<b>ProportionICUFromAll</b>	Proportion of all clinical cases that are admitted to the ICU
<b>nAsymptomatic</b>	Number of asymptomatic infections in the population
<b>nAsymptomaticChild1 to nAsymptomaticElderly</b>	Age specific asymptomatic infections in the population
<b>nMild</b>	Number of mild infections in the population (i.e. not hospitalized)
<b>nMildChild1 to nMildElderly</b>	Age specific mild infections in the population
<b>nSevere</b>	Number of severe infections in the population (i.e. those that are hospitalized and/or admitted into the ICU)
<b>nSevereChild1 to nSevereElderly</b>	Age specific severe infections in the population
<b>nClinical</b>	Number of symptomatic infections in the population (this adds up to nMild + nSevere)
<b>nClinicalChild2 to nClinicalElderly</b>	Age specific symptomatic infections in the population
<b>nClinicalOrAsymptomatic</b>	Number of symptomatic and asymptomatic infections in the population (this adds up to nClinical + nAsymptomatic)
<b>nClinicalOrAChild1 to nClinicalOrAElderly</b>	Age specific symptomatic and asymptomatic infections in the population
<b>nGenHospitalized</b>	Number of general hospitalized infections in the population
<b>nGenHospitalizedChild1 to nGenHospitalizedElderly</b>	Age specific general hospitalized infections in the population
<b>nHospitalizedAll</b>	Number of all hospitalized infections in the population including general hospitalizations and pre- and post-ICU hospitalizations
<b>nHospitalizedAllChild1 to nHospitalizedAllElderly</b>	Age specific all hospitalized infections in the population including general hospitalizations and pre- and post-ICU hospitalizations
<b>nICU</b>	Number of ICU admissions in the population
<b>nICUChild1 to nICUElderly</b>	Age specific ICU admissions in the population
<b>nDeaths</b>	Number of deaths in the population
<b>nDeathChild1 to nDeathElderly</b>	Age specific deaths in the population
<b>nSRecovered</b>	Number of symptomatic recoveries in the population
<b>nSRecoveredChild1 to nSRecoveredElderly</b>	Age specific symptomatic recoveries in the population
<b>PopulationSize</b>	Total population size (this will be defined by the number of households rather than explicitly defined)
<b>nChild1</b>	Number of agents 0 to 4 years
<b>nChild2</b>	Number of agents 5 to 9 years
<b>nChild3</b>	Number of agents 10 to 14 years
<b>nYouth</b>	Number of agents 15 to 20 years

<b>Variable</b>	<b>Description</b>
<b>nAdult1</b>	Number of agents 20 to 44 years
<b>nAdult2</b>	Number of agents 45 to 54 years
<b>nAdult3</b>	Number of agents 55 to 64 years
<b>nSenior1</b>	Number of agents 65 to 74 years
<b>nSenior2</b>	Number of agents 75 to 84 years
<b>nElderly</b>	Number of agents 85 years and over
<b>nHousehold1 to nHousehold12</b>	Number of households with 1 household members, 2 household members... up to 12 household members
<b>nSchools</b>	Number of schools
<b>nWorkplaces</b>	Number of workplaces
<b>nMixed</b>	Number of mixed age venues
<b>nAgentsInSchools</b>	Number of agents that were assigned to schools
<b>nAgentsInWorkplaces</b>	Number of agents that were assigned to workplaces
<b>nAgentsInMixedAgeVenues</b>	Number of agents that were assigned to workplaces
<b>ClosedSchools</b>	Number of schools that were closed during the simulation (if closures occurred twice or more, this is the total number of closed schools; the same school could be closed more than once)
<b>ClosedWorkplaces</b>	Number of workplaces that were closed during the simulation
<b>ClosedMixed</b>	Number of mixed age venues that were closed during the simulation
<b>nExtClosedWorkplaces</b>	Number of workplace closures triggered by the extended workplace closure event
<b>nExtClosedMixed</b>	Number of mixed age venue closures triggered by the extended mixed age venue event
<b>nCumExposedFinalNumber</b>	Number of exposed infections in the population who were exposed by traceable agents (i.e. symptomatic agents)
<b>nTimeQuarantineApplied</b>	Number of times quarantine was applied during the model run
<b>nQuarantined</b>	Number of agents with known contacts that were quarantined during the simulation
<b>nEnhanceQuarantined</b>	Number of agents with known contacts quarantined due to enhanced contact tracing
<b>nCumUExposedFinalNumber</b>	Number of exposed infections in the population who were exposed by untraceable agents (i.e. asymptomatic agents)
<b>nUnknownQuarantined</b>	Number of agents exposed by unknown contacts that were identified and quarantined (in reality, and in the model, this occurs when the additional testing intervention is applied, i.e. additional community testing of asymptomatic individuals identifying these cases and putting them in quarantine).
<b>nCumUnknownEnhanceQuarantined</b>	Number of agents with unknown contacts that were identified through additional testing and quarantined during the simulation
<b>nCumAInfQuarantined</b>	Number of asymptomatic infectious agents that were identified through additional testing and quarantined

<b>Variable</b>	<b>Description</b>
<b>nCumAInfEnhanceQuarantined</b>	Number of asymptomatic infectious agents that were identified through enhanced testing and quarantined
<b>nCumInfQuarantined</b>	Number of all infectious agents that were identified through testing and quarantined
<b>nCumInfEnhanceQuarantined</b>	Number of all infectious agents that were identified through enhanced testing and quarantined
<b>nIsolated</b>	Number of agents that were isolated because they were sick (compliant and identified)
<b>nEnhanceIsolated</b>	Number of agents that were isolated because they were sick and identified through enhanced/additional testing (compliant and identified)
<b>nHouseholdQuarantined</b>	Number of household agents who quarantined because someone in their household was sick
<b>nRepeatIsolationFinal-Number</b>	Number of household agents who also self-isolated because someone in their household was sick
<b>nIsolatedAgain</b>	Number of agents who were still infectious after 14 days of isolation and re-isolated again
<b>nQuarantineAndIsolated</b>	Number of agents who were quarantined and isolated, i.e. quarantined through contact tracing and isolated because of a family member being sick
<b>nFamilyQuarantinedAndIsolated</b>	Family members who have been quarantined and isolated
<b>nTimeSocialDistancingApplied</b>	Number of times social distancing was applied during model run
<b>nTimeClosuresApplied</b>	Number of times closures were applied during model run
<b>DeescalationTime</b>	Model run time when de-escalation event was triggered and all interventions were stopped
<b>InfectionInSchool</b>	Number of agents who were infected at school
<b>InfectionInSchoolChild1 to InfectionInSchoolElderly</b>	Age specific number of agents who were infected in school
<b>InfectionAtWork</b>	Number of agents who were infected at work
<b>InfectionAtWorkChild1 to InfectionAtWorkElderly</b>	Age specific number of agents who were infected at work
<b>InfectionAtMixed</b>	Number of agents who were infected in mixed age venues
<b>InfectionAtMixedChild1 to InfectionAtMixedElderly</b>	Age specific number of agents who were infected at mixed age venues
<b>InfectionAtHome</b>	Number of agents who were infected at home
<b>InfectionAtHomeChild1 to InfectionAtHomeElderly</b>	Age specific number of agents who were infected at home
<b>nFamSusceptible to nFamRemoved</b>	Tracking the family member health states when forced to co-isolate with infected household members
<b>MondayKid to FridayKid</b>	Tracking the kids in school for School Staggering event

Variable	Description
<b>GuardianForcedHome</b>	Number of parents who are forced to stay home with their kids (age 15 and under) when school is closed and no other household member is at home for that day
<b>NumberofExposures</b>	Number of exposure messages sent by agents (versus nCumExposed, which is the number of successfully exposed agents)
<b>ShutdownDays</b>	Number of days shutdown was imposed

## 7.2 Analysis using Stata or RStudio

After the model outputs are saved in the .csv files, further analysis can be conducted on the variables to calculate descriptive statistics and visualize the outbreak trajectory over time. There are two options to do this depending on software preference.

### 7.2.1 Analysis using Stata

1. To calculate descriptive statistics across model iterations, use the **Final Metric 245.do** Stata Do-file after importing **Final\_Metrics\_AllRuns.csv**
2. To visualise trajectories over time, import the output file of interest and run the corresponding graph code in the **Graphs for shutdown analysis.do** Stata Do-file. For example, if interested in visualizing daily incidence, import **Cum\_ClinicalOrAInfectious.csv** and run the code chunk corresponding to daily incidence.

### 7.2.2 Analysis using RStudio

1. Calculations for descriptive statistics and trajectory visualizations are contained in the R Markdown file titled **abm\_outputs.Rmd**.
2. Open the file in RStudio and click **Knit** in the top menu bar. The code will run and the outputs will load in a new window.