O.D.D. description of the COMOKIT Micro model

Projet: COMOKIT - http://comokit.org/
Version: 2.0
Date: February, 14nd 2023
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We describe in this document the COMOKIT model using the standard O.D.D. protocol[1] in its first review version.

Overview

Purpose

This model aims at simulating and comparing the application of COVID-19 spread mitigation policies at the scale of a building or a small set of buildings, the transmission of the disease being modeled at the individual scale. Its purpose is to support deciders and researchers in answering

[1] Grimm V, Berger U, DeAngelis DL, Polhill JG, Giske J, Railsback SF. The ODD protocol: A review and first update. Ecological Modelling. 2010 Nov 24;221(23):2760–8.

questions such as: Is the containment of some rooms more effective than that of an entire floor? What is the impact of wearing masks on the dynamics of the epidemic? What should be the maximum density to limit spread? What proportion of the population should be allowed to undertake activities during a lockdown?

Two case studies are provided with the model: one concerning a classic office with a second building representing the office restaurant; one concerning the hospital of Danang.

Beyond these case studies, the model has been designed as a framework generic enough to be applied to any case study as long as the correct input data is provided. A great deal of the design effort has been put on this aspect.

Entities, state variables, and scales

Scales

The simulations are executed at the scale of a set of buildings. The smallest considered spatial units are individual rooms.

The simulations are not launched from a specific starting date, but rather from the introduction of the first infected cases in the population and will run until the end of the epidemic. The simulation step is set to 1 minute.

Entities

The model is designed to simulate the COVID-19 spread at the individual scale. As a consequence, the core entity of the model is the `Individual` kind of agents (or species): it represents individual users of the buildings with their individual characteristics (age, sex, employment status) and their epidemiological status, whether they have been tested, and other epidemiological individual-dependent values (e.g. latent_time, infectious_time … c.f. the epidemiological submodel description for more details). They perform their daily activities (including going to their office, going to the restaurant, going to the meeting room…) depending on their personal agenda. This agenda is a generated set of `Activity`.

`Room` agents are spatial entities where the `Individual` agents can perform an `Activity`. A `Room` has one or several `RoomEntry` agents and several `Wall` agents. It is located at a specific floor of a `Building` agent. A specific type of Room is `Elevator`, allowing `Individual` agents to pass from one floor to another one. In addition to `Room` agents, a `Building` agent has one or several `BuildingEntry` agents. The global environment is characterized by `Building` agents, but also by one or several `AreaEntry` agents and by `PedestrianPath` agents representing the path that `Individual` agents can follow to move.

The `Individual` agent's behavior is driven by their agenda attribute that associates to some date an `Activity`. An `Activity` is mainly a way to choose the spatial unit(s) in which the `Individual` agents have to be located or to move to at each simulation step. the last type of spatial entity are the `UnitCell` agents, which allow to take into account the environmental contamination

We have also defined additional specific `Activity` species to represent the main classical kinds of `Activity`: `ActivityLeaveArea`, `ActivityGotoOffice`, `ActivityGotoRestaurant`, `ActivityGotoRoom`. Of course, customs activities can also be created from the generic `Activity` species.

All the agent species are summarized and organized on the UML diagram presented in **Figure 1**.

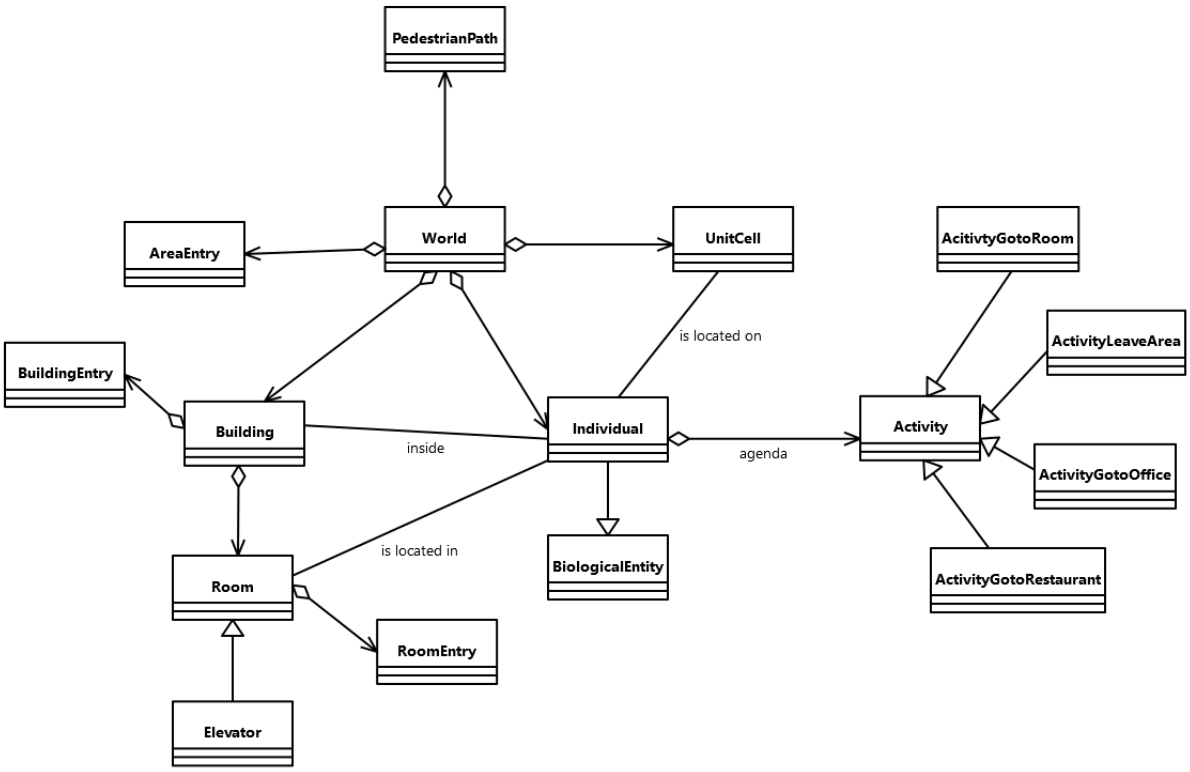

Figure 1. UML class of an overview of the COMOKIT model

Process overview and scheduling

The model simulates the spread of the COVID-19 in a population at the individual level. The dynamics of the model can be summarized by two main dynamics: the epidemic dynamics and the activities of the Individual agents, following their agenda.

There are three different pathways of infection for Individual agents: either through Individual-to-Individual transmission, through persistence of the virus in the air, and through persistence of the virus on the physical objects. When an infectious Individual is located in a building, it can release a virus load on the unit cell it is located in, which can survive several hours. In addition, it can release a virus load in the room it is located in. Individuals who will come to this unit cell/room can thus become infected by the viral load present in the unit cell/room itself. As soon as an Individual is infected, its epidemic status will be described by a set of states and transitions (given probabilities taken from the up-to-date COVID-19 literature).

A simulation step starts by the evolution of the viral load in the unit cells and in the rooms (it decreases over time, before disappearing). Then the Individual agents behave. They first evaluate whether they are infected or infect other Individuals or release virus load in their current unit cell/room. They then update their epidemic status (given the model detailed in the Sub-model Section) and their individual behavior related to mask wearing. Finally they execute their activities: they find the activity corresponding to the current time, and act in accordance.

Design Concepts

Basic principles

As far as the epidemiological dynamics is concerned, we rely on much scientific evidence that the disease could be represented by a SEIR model (44) with an infectious state that can be presymptomatic, symptomatic or asymptomatic, with a certain degree of survivability of the virus in the environment and the possibility of people being infected by it.

The individual agents' behavior is described using an activity-based approach[2]: people have a set of activities associated with some corresponding time. This agenda makes the agents move from room to room (and eventually from building to building) and enter/leave the simulated area.

Emergence

The main emergent (or at least complex to predict) results are the evolution of the number of infected cases given the different parameters that intervene in the definition of a policy.

Interaction

Individual agents can infect other Individual agents directly through contact or indirectly through room and/or unit cell contamination: Infectious Individual agents can release a viral load in a unit cell and/or in a room agent and, as the virus can survive in the Building for a period of time, a unit

[2] Chapin FS. Human activity patterns in the city: Things people do in time and in space. Wiley-Interscience; 1974. Ilägcrstrand T. What about people in regional science?. InPapers of the Regional Science Association 1970 (Vol. 24).

cell and a room agent with a viral load will possibly infect the Individual agents located in it, following the assumption that contaminated surfaces such as doorknobs, tables, on which the virus can survive, are possible transmission pathways.

Stochasticity

As we integrate in our model an heterogeneous population, and that a great deal of data is impossible to know with certainty (e.g., when infected, what is the time spent by an Individual time in each epidemiological state?), many values are randomly generated in a range of values coming from the literature.

1. At the initialization, here are the Individuals' attributes randomly generated:
    a. the distribution of individual attributes, including age and sex (when built-in synthetic population generation procedure is used),
    b. the localization of rooms for agents' activities such as gotoOffice,
    c. the series of activities for a week, i.e. agendas including time for lunch, time to go to work, and so on.
2. As far as the Individual agents' epidemiological dynamics:
    a. the test of its epidemic state follows probabilities of false positives and negatives,
    b. the fact of wearing a mask is random given a model parameter,
    c. when an Individual agent becomes infected, some epidemiological attributes are randomly computed following different distributions: its incubation period, serial interval (for presymptomatic period) and infectious period,
    d. the facts of being Symptomatic or Asymptomatic, and of dying from the disease follow some age-related epidemiological parameters,
    e. Individual factors regarding infectivity, increasing or decreasing the transmission risk of that Individual are following a random distribution
3. Concerning Individual agents' activities:
    a. When doing some activity, the choice of a room and of a target in the room can be random.

Observation

The observation interface of the COMOKIT simulations can be defined depending on the experiments' needs. The observation interface will contain a display of the spatial environment (all the buildings with their different floors and a focus on one floor of a building) and a chart plotting the evolution of the number of infected individuals over time. **Figure 2** shows an example of such an interface.

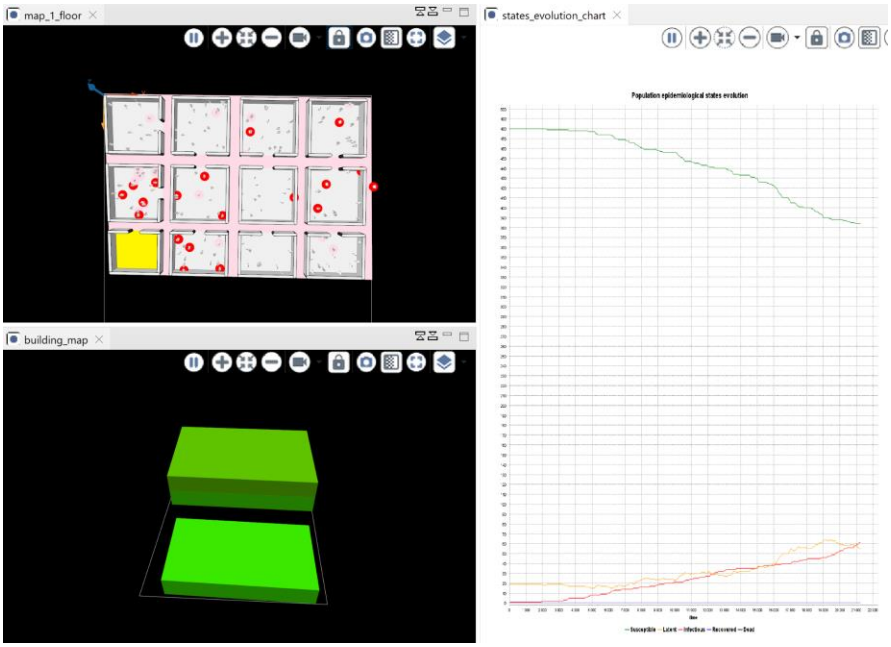

Figure 2. Example of Graphical User Interface of a COMOKIT Micro experiment on environment composed of two buildings

Details

Initialization

In order to keep the model as generic as possible, many parameters and initial values are stored in case-dependent external files. Two parameter files for epidemiological model and activity types links to building types are stored in a general purpose parameter folder. In order to use them in a custom version of COMOKIT, users should either redefine them or give the path to this folder relative to the new project. The initialization of a simulation combines reading files and assigning values to the main parameters, with synthetic population characteristics (location, social network, agenda) generators as follows:

1. Initialization of the epidemiological parameters from the associated csv file.
2. Creation of the spatial environment from files: Building, AreaRoom, Entry, Wall, BuildingEntry, RoomEntry, Elevator, PedestrianPath agents and creation of links between them.
3. Creation of 1 Activity agent for each built-in activity.
4. Creation,initialization and localisation of the Individuals synthetic population and generation of the agenda for each of them.
5. Initialization of the epidemic: a given number of Individual agents become infected: they start by being in the exposed state and their disease-related attributes are initialized (incubation and infectious times and its serial interval).

Input Data

All the input data are summarized in **Table 1** and **Table2**.

Data file	Data Type	Description
Buildings.shp	GIS shapefile	All the building geometries, with attributes, nb_floors, nb_unders.
Rooms.shp	GIS shapefile	All the room geometries, with attributes, building, floor and type
Elevators.shp	GIS shapefile	All the elevator geometries, with attributes, building and floor
Building_entries.shp	GIS shapefile	All the building entry geometries, with attribute building
Room_entries.shp	GIS shapefile	All the room entry geometries, with attributes room_id and floor
Area_entries.shp	GIS shapefile	All the area entry geometries
pedestrian_path.shp	GIS shapefile	All the pedestrian path geometries, with attributes building, floor, and area (width of the path)
Epidemiological Parameters.csv	Csv tabular file	The set of epidemic parameters for the COVID-19. See Annex1 for more details.

Table 1. Overview of the dataset

Only three input data files are mandatory: buildings.shp, boundary.shp and Epidemiological Parameters.csv.

Epidemiological parameters

The epidemiological parameter file is a table of parameters. For each of them, the following values are provided: (i) the name of the parameter, (ii) the age category lower bound (the upper bound will be defined according to the lower bound of the next age category of the parameter), (iii) whether the parameter value is given or if it has to be picked in a given probability distribution, (iv) its value (if of type given value) or the first parameter for the distribution, and (v) the second parameter (of the distribution).

Submodels

The epidemiological submodel

In our model, the disease-related state of the Individual agents follows a slightly modified SEIR model (44) using a final state machine structure (c.f. **Figure 3**). We considered the traditional

Exposed compartment as a Latent compartment, where individuals are not yet infectious. We assumed the whole population starts the simulation in a **Susceptible** state (**S**) (as this is an emergent disease, nobody is immunised). When an Individual is in contact with an Infectious agent or located in an infected building, it can become infected and move to the **Latent** state (**L**), depending on the successful transmission rate. The successful transmission rate here is defined as the probability for one contact at a given step to be infected by an Individual. The *latent period* is defined as the time period between the exposure to the virus and the time the Individual becomes infectious, whereas the *incubation period* is the period between exposition and symptom onset. The Individual agent will stay in the Latent state for a given latent period computed according to the incubation period, and the *serial interval*, which is the period between the symptom onset of the newly infected individual and a future possible infection that it will cause. Due to presymptomatic infections, this serial interval can have a negative value, which is subtracted from the incubation period to obtain the possible latent period. In the case of having a positive value, we consider the latent period as equals to the incubation period (therefore, not using the serial interval), indicating infectivity of the Individual only once symptomatic (see **Figure 4**).

Once the latent period has expired, the Individual agent will move to one of the three infectious states (whereas the traditional SEIR model contains a single one): it can be **asymptomatic** (**Ia**), **presymptomatic** (**Ip**) or **symptomatic** (**Is**). If the serial interval value was negative, the Individual agent will be presymptomatic for a short period equals the absolute value of the serial interval before moving to the symptomatic state, therefore having an incubation period equals the latent period plus the presymptomatic period. The agent will stay in these states during the serial interval (for presymptomatic) and the infectious period for symptomatic and asymptomatic. The transmission risk of a susceptible individual will depend on being symptomatic or asymptomatic, and will be multiplied by a viral factor which is different for each Individual. We consider that asymptomatic and presymptomatic Individuals share the same transmission rate.

Once the infectious period is over, Individual agents reach the **Removed** (**R**) state, representing all individuals that have been infected, but are not infectious anymore. To represent deaths and recoveries, we decided to consider another variable, *clinical_status*, which represents the current clinical status of the Individual agent.

Individual agents begin with a clinical status set to not needing hospitalization ($\mathbf{N_H}$) (see **Figure 5**). Individuals in the asymptomatic, latent or presymptomatic states will still not need hospitalization. However, symptomatic Individuals have a probability of needing to be hospitalised (and thus move to the clinical status need_hospitalisation $\mathbf{H_N}$). Symptomatic individuals needing to be hospitalised have a probability of needing to be admitted in an Intensive Care Unit (ICU) (and thus to be in the clinical status need_ICU $\mathbf{H_I}$), and therefore, die from the disease (corresponding to the clinical status dead $\mathbf{R_D}$). If the Individual agent is not being taken to a hospital before the end of its expected period needing ICU, it will be considered as dead due to lack of treatment. In the case the agent will never need ICU and has not been taken to a hospital, it will be considered as recovered ($\mathbf{R_R}$). For Individuals taken by hospitals, the hospital will decide on the clinical status according to the probability of dying for ICU cases. For hospitalised cases,

they are considered recovered once they do not show any symptoms (i.e. not in the state symptomatic) and are tested negative for x consecutive days.

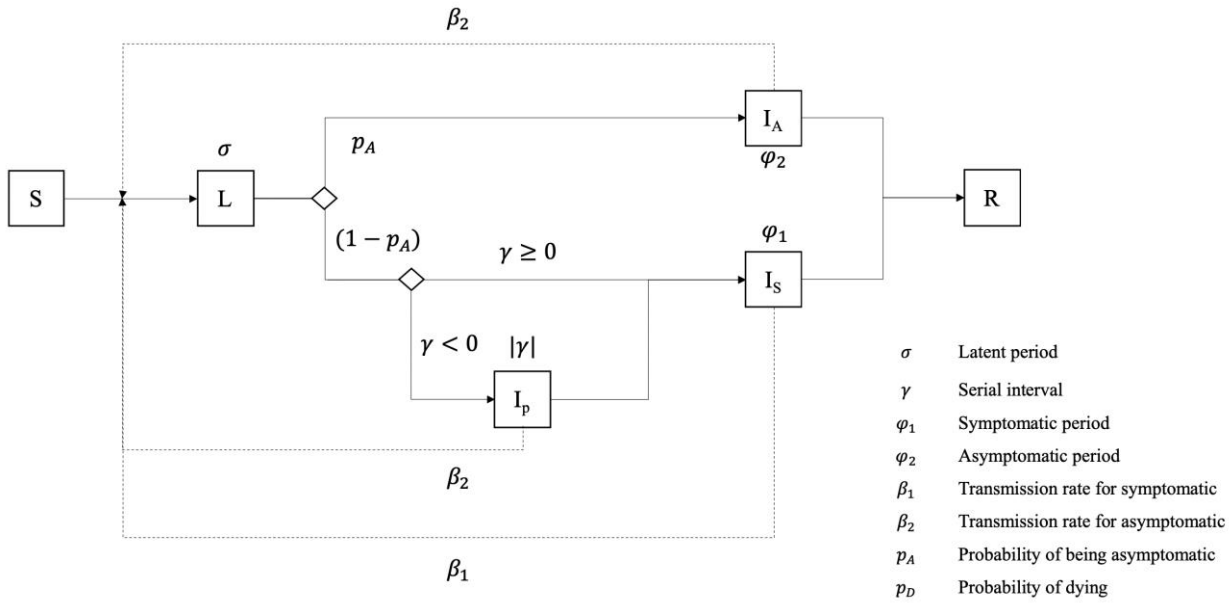

Figure 3. Epidemiological model of the Individual agent.

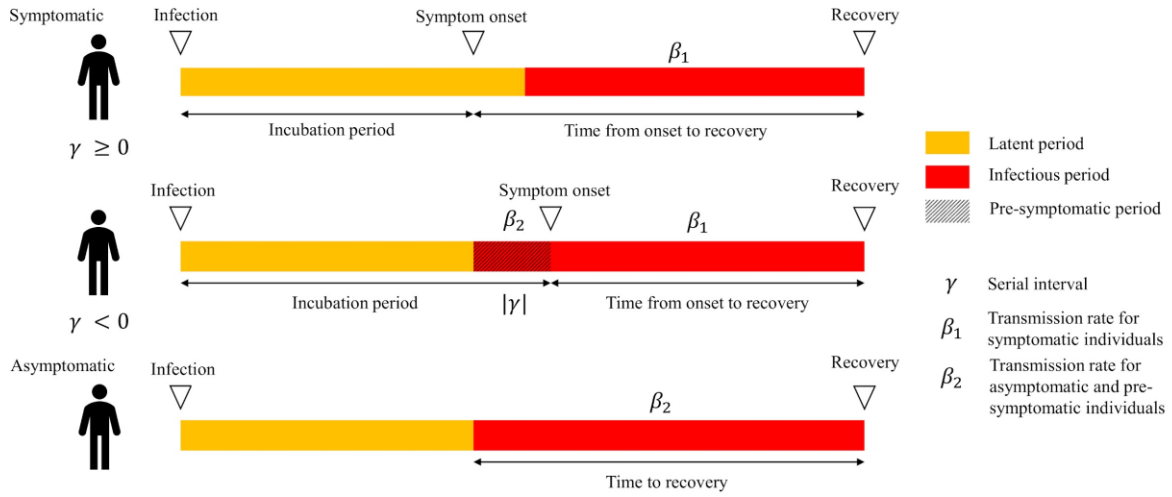

Figure 4. Illustration of the durations in different states (and the associated transmission rates) for both Symptomatic and Asymptomatic Individuals.

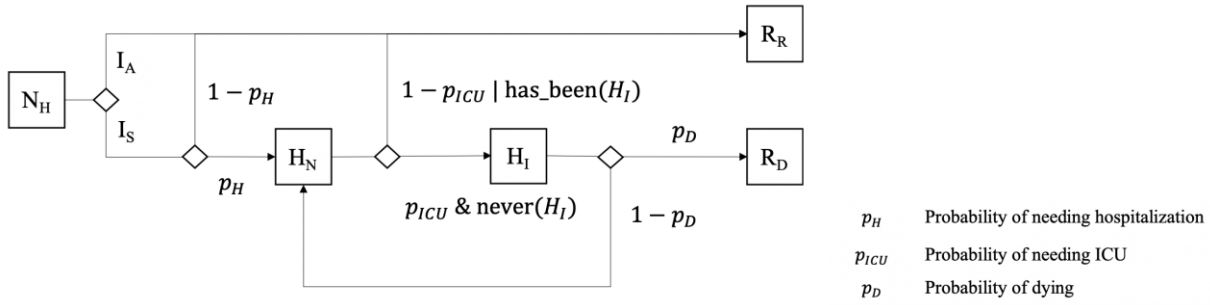

Figure 5. Hospitalisation model of the Individual agent.

The various incubation, serial and infectious periods are Individual dependent and are randomly picked following various distributions.

Given a lack of data, we made several assumptions in the model related to parameters (and in particular to their heterogeneity in the population):

- The incubation period does not differ for different age categories.
- The successful contact rate for human to human and environment transmission (i.e. the rate of Individuals becoming Latent after being in contact with an infectious one) does not differ for different age categories.
- The proportion of asymptomatic individuals does not differ for different age categories.
- The successful contact rate does not differ during the infectious period.
- Asymptomatic and symptomatic individuals share the same infectious period distribution.
- The individual factor of the transmission risk does not differ for different age categories

Finally this model of the epidemic states evolution makes also several assumptions:

- The serial interval can be used as a proxy to get the presymptomatic part of the infectious period.
- Individuals could be infected by a contaminated environment, and for a maximal viral contamination in one building, the successful transmission rate is the same as one infectious Individual.
- Sex does not have an impact on the epidemiological model.
- The viral release of an individual in the environment (in our model, in Buildings) is the same for all infectious individuals.
- Presymptomatic and asymptomatic individuals share the same transmission successful contact rate.
- Masks do not deliver any protection, but rather reduce the successful contact rate of an infectious individual and its viral release in the environment.
- Recovered Individuals are totally immunised against the infection.

- Infection can lead to death only for Individuals expressing a need for intensive care.
- Testing is performed only for virus isolation, not antibodies, therefore, recovered people are not considered positive.

Daily Activities

Once weekly and daily agendas have been created at initialization, Individual agents have only to get, at each simulation step, the Activity corresponding to the current day and current hour, asks the Authority agent's authorization to perform it, finds a building associated with the Activity, and moves in it. In addition, the agent will ask the Authority for the number of individuals it can perform the Activity with. It will then pick randomly this number among its possible Activity fellowers, and store them during the Activity period. This set of agents will be used in the disease spread as possible infectees with a higher probability.

The time is managed internally by the GAMA platform: from the simulation step duration set to 1 hour and a simulation starting date, the simulation will automatically compute the current day and hour.

Annex 1: Description of epidemiological parameters and input data related to COVID-19 used in the COMOKIT model

We make here a distinction between **parameters** (whose values are modified to define an experiment scenario) and **input data** (whose values are given from the literature).

Parameters

The parameters can either be used to define an exploration (e.g. to compare epidemics with and without transmission in buildings), or are only assumed and need to be investigated through a sensitivity analysis.

Parameter	Detail	Parameter_1	Parameter_2	Used for
Transmission_human	Fixed	true		Exploration
Transmission_building	Fixed	true		Exploration
Successful_contact_rate_building	Fixed	0.170071		Sensitivity
Basic_viral_release	Fixed	3		Sensitivity
Basic_viral_decrease	Fixed	0.01375		Sensitivity
Proportion_wearing_mask	Fixed	0		Exploration
Reduction_wearing_mask	Fixed	0.5		Exploration
proba_outside_contamination_per_hour	Fixed	0.0		Sensitivity

Input data

Parameter	Age	Detail	Parameter_1	Parameter_2	Region	Source
Successful_contact_rate_human	0	Fixed	0.034014			Derived from R0
Reduction_asymptomatic	0	Fixed	0.45		China	(1)
Proportion_asymptomatic	0	Fixed	0.28		Japan cruise	(2)
Probability_true_positive	0	Fixed	1.0			(3)
Probability_true_negative	0	Fixed	0.91			(3)
Incubation_period_symptomatic	0	Lognormal	1.57	0.65	China, Shenzhen	(4)
Incubation_period_asymptomatic	0	Lognormal	1.57	0.65		Assumed
Serial_interval	0	Normal	3.96	4.75	China not Hubei	(5)
Proportion_hospitalization	0	Fixed	0.025		USA	(6)
Proportion_hospitalization	20	Fixed	0.208		USA	(6)
Proportion_hospitalization	45	Fixed	0.283		USA	(6)
Proportion_hospitalization	55	Fixed	0.301		USA	(6)
Proportion_hospitalization	65	Fixed	0.435		USA	(6)
Proportion_hospitalization	75	Fixed	0.587		USA	(6)
Proportion_hospitalization	85	Fixed	0.703		USA	(6)
Proportion_icu	0	Fixed	0		USA	(6)
Proportion_icu	20	Fixed	0.2019		USA	(6)
Proportion_icu	45	Fixed	0.3675		USA	(6)
Proportion_icu	55	Fixed	0.3721		USA	(6)
Proportion_icu	65	Fixed	0.4322		USA	(6)
Proportion_icu	75	Fixed	0.5281		USA	(6)
Proportion_icu	85	Fixed	0.4125		USA	(6)
Proportion_death_symptomatic	0	Fixed	0		USA	(6)
Proportion_death_symptomatic	20	Fixed	0.0476		USA	(6)
Proportion_death_symptomatic	45	Fixed	0.0769		USA	(6)
Proportion_death_symptomatic	55	Fixed	0.2321		USA	(6)
Proportion_death_symptomatic	65	Fixed	0.2606		USA	(6)
Proportion_death_symptomatic	75	Fixed	0.3387		USA	(6)
Proportion_death_symptomatic	85	Fixed	0.9414		USA	(6)
Infectious_period_symptomatic	0	Lognormal	2.8622	0.0685	China, Shenzhen	(4)
Infectious_period_symptomatic	10	Lognormal	2.949688	0.094	China, Shenzhen	(4)
Infectious_period_symptomatic	20	Lognormal	2.95491	0.047	China, Shenzhen	(4)
Infectious_period_symptomatic	30	Lognormal	2.95491	0.033	China, Shenzhen	(4)
Infectious_period_symptomatic	40	Lognormal	3.072693	0.04	China, Shenzhen	(4)
Infectious_period_symptomatic	50	Lognormal	3.109061	0.037	China, Shenzhen	(4)
Infectious_period_symptomatic	60	Lognormal	3.131137	0.039	China, Shenzhen	(4)

Infectious_period_symptomatic	70	Lognormal	3.113515	0.08	China, Shenzhen	(4)
Infectious_period_asymptomatic	0	Lognormal	2.8622	0.0685		Assumed
Infectious_period_asymptomatic	10	Lognormal	2.949688	0.094		Assumed
Infectious_period_asymptomatic	20	Lognormal	2.95491	0.047		Assumed
Infectious_period_asymptomatic	30	Lognormal	2.95491	0.033		Assumed
Infectious_period_asymptomatic	40	Lognormal	3.072693	0.04		Assumed
Infectious_period_asymptomatic	50	Lognormal	3.109061	0.037		Assumed
Infectious_period_asymptomatic	60	Lognormal	3.131137	0.039		Assumed
Infectious_period_asymptomatic	70	Lognormal	3.113515	0.08		Assumed
Onset_to_hospitalization	0	Lognormal	1.23	0.79		
Hospitalization_to_ICU	0	Normal	7	5.9	China, Wuhan	(7)
Stay_ICU	0	Normal	8	5.9	China, Wuhan	(8)

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