Conceptual Model ASSOCC

(Agent-based Social Simulation of the Coronavirus Crisis)

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1 Purpose

The purpose of this simulation lies in providing support for stakeholders for making informed decisions regarding the management of the COVID-19 disease. The simulation is a sandbox that allows many different types of scenarios to be tested. In this regard, the core aspects that are part of the model are driven by both: *1) the important features raised by public media and stakeholders* (e.g. public measures, shortages, flattening the curve) and *2) social aspects from psychology and sociology that are acknowledged to be of importance in a crisis* (e.g. needs, social networks, practices, habits, and values).

Regarding other models, ASSOCC[1] aims to provide *detailed models,* capable of capturing the often-overlapping causes of the emerging phenomena, whereas most of available simulations focus on narrower aspects that may be more solidly grounded in statistics, but often fail to account for underlying causes. This way, ASSOCC offers a richer opportunity for studying the effects of decisions on many aspects (e.g. psychology, sociology, epidemiology, economy), as well as increasing the resilience of observations provided by the system by accounting for more sources of influence. This multi model approach allows us to see how health, the social system and the economic system get influenced when we adjust an aspect or introduce different types of government policies.

The R0 factor is a good illustration of this complementary aim (i.e. the average total number of people infected by the first infected persons before anti epidemic measures against the specific disease have been taken)[2]. Many models use the R0 factor as an input variable for describing disease dynamics; whereas for the ASSOCC model (and in the real-world), R0 is an output or control variable, which depends on the interplay of other variables, such as the degree of infectiosity of people and their amount of contact. This way, the ASSOCC model aims to play with more sensitive and advanced variables (e.g. the density of the population, the dynamics of contacts between people) and the subtle interplay of their dynamics (e.g. the influence of culture on R0 correlated with how public measures impact people psychological dynamics).

This document, ODD (Overview, Design concepts, and Details) describes the agent-based model underlying the ASSOCC framework. We follow part of the standardized ODD protocol as described in the ODD Protocol first edition[3].

[1] (n.d.). ASSOCC. Retrieved June 10, 2020, from https://simassocc.org/
[2] (2007, March 14). Theory versus Data: How to Calculate R0? - PLoS. Retrieved June 9, 2020, from https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0000282
[3] (2010, November 24). The ODD protocol: A review and first update - ScienceDirect. Retrieved June 9, 2020, from https://www.sciencedirect.com/science/article/pii/S030438001000414X

2 The elements and submodels

This chapter describes the elements and submodels in the simulation in a general way. The exact parameters and their values are not described as this explodes the number of pages, and since the simulation is still adjusted maintaining all the parameters in the ODD will be infeasible. Instead the elements are described and a link to more detailed documentation will be provided. This document thus deviates from the ODD in such a way that we take the entities, state variables, scales section together with the scheduling and submodels.

2.1 Simulation overview

The simulation represents a city and contains agents (representing people), homes, buildings, and leisure places. Figure 1 shows an overview of the city with the agents (and traces of their recent movements). The image is generated from the unity interface. The school and university are referred to with the same type of building. There is not only public leisure, but also private leisure which happens at the homes of people.

Figure 1: Unity interface of netlogo simulation

2.1.1 Elements

There are a number of elements influencing the agents' behavior. Figure 2 shows a general overview. These elements are described in the upcoming subsections.

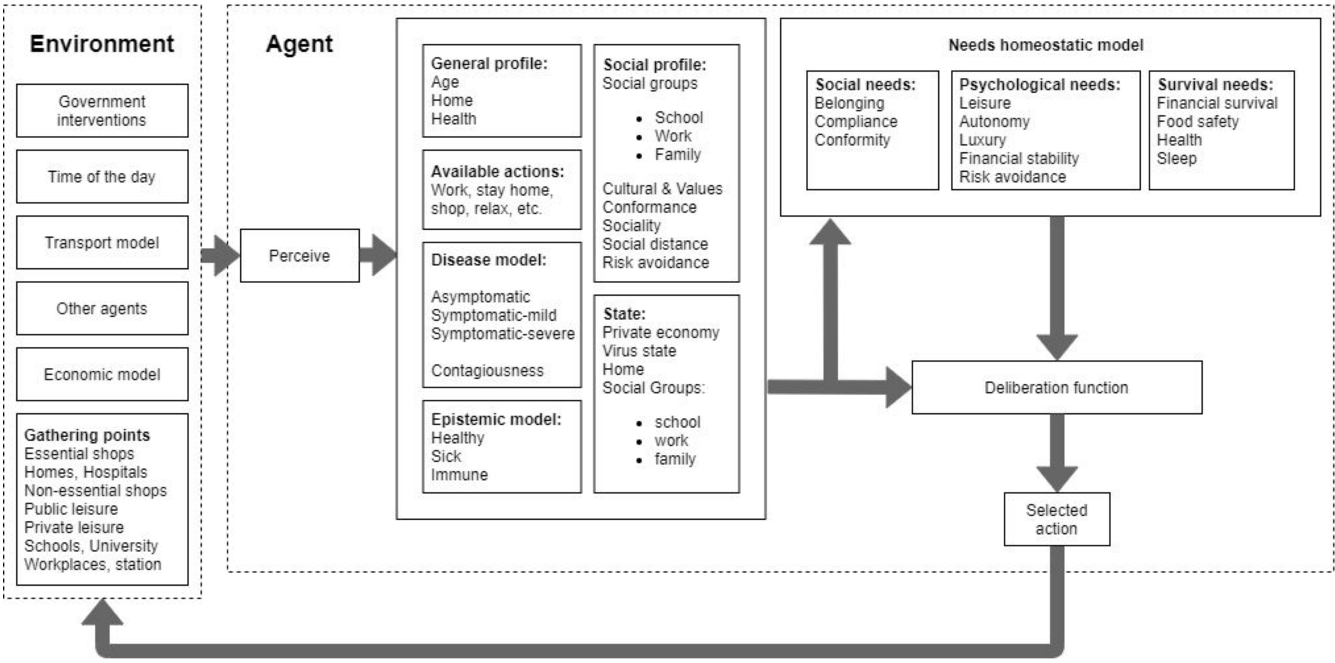

Figure 2: High-level overview of the model's components

2.1.2 Temporal scale

The day is divided into four slices in the simulation: morning, afternoon, evening and night. Each of them have different implications for the agents. For example, in the night the agents sleep, while in the morning they go to their jobs or other places. The part of the day changes every tick, thus each day consists of four ticks. The days of the week are explicitly modelled and there is a difference between weekdays (when people work) and weekend days (no working).

2.1.3 Spatial scale

The gathering points represent the spatial model. They do not have specific coordinates that influence the agents' decision making. The spatial scale could be compared to the size of a city.

2.1.4 Software

The model is implemented in Netlogo 6.1.1. Since the Netlogo interface is somewhat limited we also developed an interface model in Unity. This is shown in figure 1. The output data of the model is processed in R.

2.2 Buildings and places (gathering points)

Figure 1 from the previous section already gives an indication of the different types of buildings and places, which are also called gathering points. We made places that are most relevant for policy makers. For example a difference between essential and non-essential shops, as this allows the closing of specific types of shops. The workplaces are an abstraction of for example offices and factories as they seem roughly the same from the perspective of disease spreading. In these points the agents come into contact with each other and could infect each other. As a side note, the agents can also infect each other when traveling between gathering points, but this is described in the section transport model. As a simplification all agents engaged in a gathering point are assumed to be (equally) in contact with all others that are also engaged within these gathering points. Gathering points are at the core of the *proxemics* model (a central factor for virus propagation in the disease model). The table below shows all the gathering points with a short description.

Gathering Point	**Description**
Essential shops*	This is the place where agents buy food, they have to do this every once in a while.
Homes*	The agents live in their homes, they are always at home during the night to sleep. The homes can be used as a workplace if the agent has to be in quarantine.
Hospitals*	The hospital has some workers and treats people who get severely infected, if they have enough capacity (number of beds).
Non-essential shops*	With non-essential shopping agents can satisfy the need for *luxury*.
Public Leisure Places	The public leisure places represent places such as parks where everyone can go to. The needs Self-Esteem, compliance are satisfied by going there. However risk-avoidance and safety depletes.
Private Leisure Places	These are places where people can meet with their friends. In the unity interface they are represented as the homes of people.
Schools*	The youth go to school during working days. Needs such as compliance and autonomy are satisfied here.
University groups/faculties*	The students go to the university and can also satisfy autonomy and compliance here.

Workplaces*	Where most of the worker agents work. Many needs can be satisfied through going to work.
Station/airport (away)	This represents agents traveling outside of the city.

✱ Indicates that it is a potential workplace for worker agents

2.2.1 Household composition

Agents living together are considered a household. Different kinds of households with different implications exist:

Type	Implications
Adults rooming together	Two agents: either workers or students
Retired couple	Two agents: both retirees
Family	Four agents: two workers and two children
Multi-generational living	Six agents: two workers, two children and two retirees

Furthermore, different distributions representing different countries are predefined and can be selected. As of now, the following four region settings have been implemented:

- Belgium, Canada, Germany, Great Britain, France, Italy, Korea South, Netherlands, Norway, Spain, Singapore, Sweden, U.S.A.

Statistical data that has been used for the definition of the scenarios comes from the UN report "Household Size and Composition Around the World 2017" [4]. Based on that data the percentage of household type is tied to the countries.

For more information about the household composition see the Supplement scenario 2: Household Composition. This supplement includes a table of the distribution of different types of housing.

2.3 The people (agents)

The following table contains the variables for the agents. There are 300 agents for fast-testing and 1.000 agents for the more extensive runs. The agents get spawned with a fixed age (see table), a household (see Household composition) with house members and get a social network assigned. They perform their daily routines (based on the needs model), occasionally travel outside of the city and can get infected by the disease through contacts. Some of the more important variables are described in the table.

[4] (n.d.). Household Size and Composition Around the World 2017. Retrieved June 1, 2020, from https://www.un.org/en/development/desa/population/publications/pdf/ageing/household_size_and_composition_around_the_world_2017_data_booklet.pdf

Variable Name	Description
Age	Age group of the agent. The values are: youth (0-19), student (20-29), worker (30-69), retired (70+)
Disease status	An agent can have a certain state of the disease, this is in more detail described in the disease model section.
Home	The place where the agent lives
Work	The places where the agent works (or goes to school/university in the case of youth/student)
Essential shops	A list of essential shops the agent uses to buy food

2.3.1 Daily schedule

The agents have an activity schedule dependent on their age group and type of day shown in the table below. The schedules differentiate workdays and weekends for everyone except retired. On the weekends all agents have free choice, this means activities such as leisure at either private or public leisure, essential or non-essential shopping or being at home. The youth does not go shopping and can therefore only be at home or do leisure activities when they do not go to school. The schedule can of course change due to government policies, or when an agent or agents from the same household as the agent get infected.

Functional group	Morning	Afternoon	Evening	Night
Youth (workdays)	School	School	Home/Leisure	Home
Youth (weekends)	Home/Leisure	Home/Leisure	Home/Leisure	Home
Student (workdays)	University	University	Free choice	Home
Student (weekends)	Free choice	Free choice	Free choice	Home
Worker (workdays)	Work	Work	Free choice	Home
Worker (weekends)	Free choice	Free choice	Free choice	Home
Retired (always)	Free choice	Free choice	Free choice	Home

2.4 Decision-Making

2.4.1 Needs

The agents make their decisions based on their needs. The needs that the agents have, are modelled using the so-called water tank model[5]. This means that every need is represented by a number between 0 and 1, which slowly decreases every tick using a decay function. The needs are inspired by Maslow's needs, however the strict hierarchical structure is not used. With the exception of physical needs (sleep, health, financial survival and food safety) which do get a higher weighting than the rest. The different needs can be given different importance by each agent and are determined by the cultural background chosen for the simulation, which is specified in the cultural model. The exact values are taken from Hofstede Insights[6].

The needs influence the activities the agents go to. Some activities are not possible for example going to the shop when the shop is closed. At every tick the agents evaluate the possible activities for their need satisfaction. The action that satisfies the needs the best is executed. This may sound like agents will go to leisure places during work times however working has many needs it satisfies such as financial needs, compliance, belonging (if friends are there and autonomy. So only in exceptional situations will an agent not work. The schedule in the table above determines when work is possible. The same mechanic applies to going to school or the university (however not satisfying financial needs).

Since one of the needs will be a need for compliance, this system allows for both rule following, and rule breaking. If you adhere to a rule, the value of your need for compliance goes up, but if you break it, the value goes down. This means that agents can decide to break a rule if their highest desired need cannot be satisfied within the currently given rules. Thus, it can be possible that different needs interfere with each other. Furthermore, current living situations, like living alone or doing home office, will be taken into account and also influence the needs of an agent. The needs implemented in our model are:

Need	**Description**
Autonomy	The need of being able to have a choice in what action to do. This freedom of choice can be limited by government interventions.
Belonging	The need to be with friends or relatives and engage in the same activities.
Compliance	The need to follow rules and imposed measures. For example, if working from home is recommended an agent with a high need for

[5] (n.d.). Modeling Culturally-Influenced Decisions | Semantic Scholar. Retrieved June 1, 2020, from https://www.semanticscholar.org/paper/Modeling-Culturally-Influenced-Decisions-Vanh%C3%A9e-Dignum/cddd8fa353a4bd8c0e9459b25094e79b49847467
[6] (n.d.). Hofstede Insights. Retrieved June 1, 2020, from https://www.hofstede-insights.com/

	compliance will gain satisfaction from staying at home and working from there.
Conformity	The social need of choosing an action that the majority of agents in its network has previously chosen.
Financial-stability	The need of having enough money to live a “good” life, e.g. to spend on “luxurious” goods, in addition to the essentials needed to survive.
Financial-survival	The need of having enough money to buy food and other essentials to survive.
Food-safety	The need of having enough food at home.
Health	The need to stay healthy. When agents believe that they are infected, they want to either stay home or go to the hospital.
Leisure	The need of people to have leisure time, e.g. relaxing. Resting (i.e. sleeping) at home is possible as well but satisfies the need less compared to relaxing at a place.
Luxury	The need of buying items which are not essential to survive, like jewelry for example.
Risk avoidance	The need of avoiding risk for one self and the society. The satisfaction of this need depends on the contagion status of the agent and the amount of people at a gathering point. Furthermore, social-distancing is taken into account.
Sleep	The need of an agent to sleep which is satisfied every night by sleeping. Furthermore, it is modeled that sleep when being sick is not as restful as when being healthy.

A schematic overview of the needs model can be seen in Supplement 3 - Needs model.

2.4.2 Culture & Values

The ASSOCC model also contains a module that is built specifically to simulate the effects that culture may have on the spread and mortality of the coronavirus[7]. This cultural submodel also enables users to explore the cross-country differences in the development and impact of the virus.

It is hypothesized that culture influences the values that agents hold. Specifically, culture informs the ranking or relative importance ascribed to a particular set of values by a given agent. Culture serves as a blueprint for agent’s to base their value systems on. Culture is

[7] Gelfand, M., Jackson, J. C., Pan, X., Nau, D., Dagher, M., & Chiu, C. Y. (2020). Cultural and Institutional Factors Predicting the Infection Rate and Mortality Likelihood of the COVID-19 Pandemic.

operationalized using the Hofstede Dimensions model[8] and is country-based[9]. Values are operationalized using the Basic Value Theory of Schwartz[10]. Linking the country-level Hofstede Dimensions with agent-level Schwartz Values is done on the basis of theoretical work[11],[12] and empirical data[13]. The degree to which agents base their value systems on the country-based scores of the Hofstede Dimensions is moderated by the country's cultural tightness. Cultural tightness dictates the structural similarity in value systems of agents within a population and is calibrated on the basis of findings presented by Gelfand et al. (2011)[14] and Uz (2015)[15]. In doing so, ASSOCC is able to represent both inter- and intra-cultural variation in agent value systems.

As noted, any given agent holds a set of values which dictates what its perceptions are of desirable states of reality (i.e. how reality *ought* to be). Values determine what an agent finds important, desireable or valuable. Values influence the agent's needs which in turn determine the agent's behavior. Ultimately, the agent's behavior determines how the virus is able to spread within an agent population over a certain span of time. Moreover, values may influence the social network topology via a process of preferential attachment (see section: Social Network Model), thereby influencing the way in which the virus percolates through the agent population.

For more information about the cultural model one could look at the Supplement 1 - The conceptual cultural model, which contains more detail and grounding in literature.

2.5 Disease model

We replicated the disease model from an epidemiological Covid-19 model made by researchers from Oxford[16]. This model takes into account that not everyone has the same disease severity, e.g. some people stay asymptomatic while others get severely ill. It divides into one of three disease processes. These are 1) stay asymptomatic through the whole infected period, 2) become mildly symptomatic and 3) become severely symptomatic (with possible hospitalization and possible death). The states are represented in the table below.

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[8] https://geerthofstede.com/culture-geert-hofstede-gert-jan-hofstede/6d-model-of-national-culture/
[9] https://www.hofstede-insights.com/product/compare-countries/
[10] Schwartz, S. H. (2012). An overview of the Schwartz theory of basic values. Online readings in Psychology and Culture, 2(1), 2307-0919.
[11] Vanhée, L., Dignum, F., & Ferber, J. (2014, May). Modeling culturally-influenced decisions. In International Workshop on Multi-Agent Systems and Agent-Based Simulation (pp. 55-71). Springer, Cham.
[12] Mercuur, R., Dignum, V., & Jonker, C. (2019). The value of values and norms in social simulation. Journal of Artificial Societies and Social Simulation, 22(1).
[13] http://www.worldvaluessurvey.org/wvs.jsp, https://www.europeansocialsurvey.org/
[14] Gelfand, M. J., Raver, J. L., Nishii, L., Leslie, L. M., Lun, J., Lim, B. C., ... & Aycan, Z. (2011). Differences between tight and loose cultures: A 33-nation study. science, 332(6033), 1100-1104.
[15] Uz, I. (2015). The index of cultural tightness and looseness among 68 countries. Journal of Cross-Cultural Psychology, 46(3), 319-335.
[16] "Effective Configurations of a Digital Contact Tracing App: A ...." 16 Apr. 2020, https://cdn.theconversation.com/static_files/files/1009/Report_-_Effective_App_Configurations.pdf?1587531217. Accessed 2 Jun. 2020.

Variable Name	Description
Infection state	The infection status of an agent is given by this variable. Most agents start out healthy and will progress through these stages when getting infected. The exact flow of stages see Appendix A - Disease model (Oxford). 1. healthy, just-contaminated a. asymptomatic-to-recovery b. pre-symptomatic-to-mild, mild-to-rec c. pre-symptomatic-to-severe, severe-to-rec, severe-to-hospital, hospital-to-death, hospital-to-rec, dead 2. immune

All people who survive the disease become immune after which they cannot be reinfected again for the remaining part of the simulation.

2.5.1 Contagiousness

The disease spreads through interaction between agents. The agents that are in the same gathering point (including vehicles) are exposed to a risk of infecting each other. This is dependent on the number of (infected) people at the gathering point, the density set for that type of gathering point and the contagiousness of the infected agent. This contagiousness varies over time, as it is dependent on a gamma distribution. An agent just infected will be minimally contagious, over time contagiousness is built up, and gradually loses contagiousness after the peak. We have the same parameter settings as in the Oxford model. Further more asymptomatic only have 0.29 of the contagiousness and symptomatic only 0.48 of the contagiousness when compared with the severely infected.

2.5.2 Epistemic model

In addition to the actual disease model, an epistemic model is implemented in the agents. The agent can have the following beliefs about himself/herself: healthy, infected, or immune. However this does not necessarily have to entail the true state of the agent. An agent can believe it is healthy while actually being sick. However also the other way around. When an agent believes it has been sick and not shows any symptoms anymore, it will believe it is immune.

2.6 Social network

An agent is part of a social network. Three types of social networks are distinguished: the friends, family and work network. The generation of friend networks is based on the homophily principle[17], so similarities in values and age are taken into account. At the setup of

[17] "Birds of a Feather: Homophily in Social Networks - Annual ...." https://www.annualreviews.org/doi/pdf/10.1146/annurev.soc.27.1.415. Accessed 17 Jun. 2020.

the simulation the euclidean similarity with other agents at the same private leisure place, school, or university is calculated. Then, the seven agents who are most similar and have the same age are chosen to become friends. Other agents in such a network can be referred to as friends of each other. One agent can be part of multiple social networks. Given the fact that agents can be part of multiple social networks, it can be possible that agents have more than seven friends. The family consists of all the agents that live in the same household. The work-related network consists of all the agents that work at the same place.

Agents have a memory to keep track of what others in their network previously did. The memory consists of actions in combination with motives. These are taken into account when the expected satisfaction gains for conformity and belonging are computed. We distinguish three types of memories: two for the behavior of the social network for both weekdays and weekends, as action during weekdays differ from actions during the weekdays, and one for the work related behavior of colleagues during the weekdays. Each memory consists of four elements, one for each slice of the day. Only the action that is chosen by the majority is saved.

For more information see Supplement 4 - Social Network.

2.7 Economic model

In order to ensure a realistic simulation for the effects on a society, it is necessary to incorporate an economic model in the simulation. What good is not getting sick if you can't buy food? The economic model is split in a micro economic model and a macro economic model. The reasoning behind this is mainly practical: modelling a full economy on the detailed level that we need is unfeasible, but we do want to see macro economic effects.

2.7.1 Microeconomic

The microeconomic system (also referred to as local economy) is based on the cycle of income and labour (figure 3). The youth is not part of the economic process. It is simplified in a way that their parents are paying for them. Students and retired agents do not go to work. They are subsidized by the government. The workers can work at some gathering points: essential-shops, non-essential-shops, workplaces, hospitals, schools and universities.

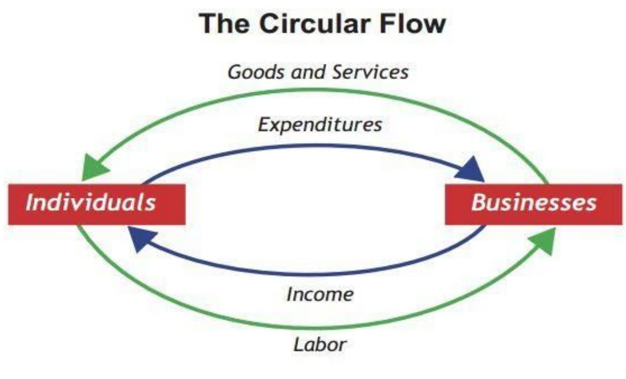

Figure 3: Cycle of income and labour

It is a closed system with the total amount of capital depending on the initialized amounts for the different entities in the simulation. The system is based on the water tank model as it uses a “capital” water tank to represent the amount of capital an agent has. The government can give money to agents and has a very large money pool to prevent them from running out.

The economic model is described in more detail in Supplement 5 - Economy for Covid-19 ABM.

2.8 Transport model

To take the probability into account of getting infected on the way between different locations (e.g., on the way to or from work), a transport module was added to the simulation model. When agents change location, there is a certain probability for taking a specific transport mode. The probability is different for different age groups.

Currently, three different modes of travel exist: public transport (bus, train), ride sharing (taxi, uber, car-pooling), and solo transport (own car, bike, walk). The agents have different probabilities of using one of the three different modes of travel.

The transport phase occurs between the activity-selection phase and the execution of this activity. At the end of this phase, we record the following variables, which will then be used by the contagion model:

- did the agent go out (check for general travelling infection)
- did the agent have to wait for transport (check for “queuing” infection)
- which mode of transport and who the agent travels with? (check for “gathering point infection”

The full transport model is not yet implemented in the main netlogo code. However the full conceptual model can be found in the following supplement.

For more information about the transport model see Supplement 6 - Transport model.

2.9 Government guidelines and interventions

The simulation contains a number of government interventions. This is not a complete list however it will give an idea of what kind of policies can be expected.

Policy	**Description**
Social Distancing	Agents are required to keep a certain distance to other agents (except household members), e.g. 2 meters. If this is enabled there is a smaller risk of agents infecting each other.

Self-Isolation	Agents that have Covid-19 should stay at home if possible (including home-office), but are still allowed to go shopping.
Shielding elderly	The elderly could be placed in isolation as they are the most vulnerable and more likely to die.
Home-office	The agents should work from home. This is only possible for people who work at some workplaces.
Closing specific gathering points	Closing gathering points, such as schools, leisure places or non-essential shops, may prevent people not in the same social network from infecting each other.
Lockdown	Every citizen is supposed to stay at home for a certain time period, e.g. 35 days.
Testing for disease	This could be random testing but also trace testing. Agents tested positive are put into quarantine.
Combination of policies	A phases system can enable different policies at the specific times or conditions such as number of infections.

The policies are generated when making scenarios. Scenarios are small simulation experiments made to analyze a specific country/strategy/aspect of the model. See Appendix B - Scenarios

2.10 Interface

The Netlogo interface can be quite overwhelming for people unfamiliar with it, especially with complex models with many parameters. To improve our communication of the model, we developed an interface using Unity that serves as an overlay for the Netlogo model. In Figure 1 that showed a screenshot of the interface, it can be seen that agents are actually visible and actually move around from gathering point to gathering point. The interface also makes it easy to select a scenario, for example testing the effect of closing schools, and run it directly. While there are many possibilities with the Netlogo interface, it is much easier to do in Unity. Our interface contains different types of plots and it is also interactive, e.g. agents can be easily selected and inspected. Figure 4 shows some plots made with the Unity interface.

Figure 4: Unity interface plots

The Unity interface starts Netlogo automatically and communicates with netlogo to be able to show the data. In order to establish communication between Unity and Netlogo we make use of the Java API for Netlogo. The Unity app is the one to start the Java app (through sockets) and initiates all communications, sending commands (including the command for the simulation to step forward) and requests for data. The Java application controls the netlogo simulation. After the setup of Netlogo, the Unity app gives a command to move the simulation forward and updates its agents based on the data received.

3 Design Concepts

3.1 Basic principles

The model is mainly based on social theories such as social practices, needs, activities, culture and more. In addition to this the model contains an economic model and disease model which allows spread from person to person through interactions. The modeling approach is to start simple and abstract while iteratively increasing the complexity of the model based on the importance of new concepts or where the model was lacking.

3.2 Emergence

Complex behavior of the agents emerges from their needs model. They will perform their daily life and visit a variety of places and people. The needs model also allows for agents breaking the rules of the government such as staying in quarantine. From this dynamic social life we expect an emergence of virus spread as agents get into contact with other agents on a regular basis. Dependent on the policies introduced by the government there could be different numbers of people infected and less or more casualties.

3.3 Adaptation

The needs model is the main drive of behavior of the agents. With no interventions or disease they are able to satisfy their needs mostly. However when interventions limit their behavior or disease limits their capabilities some needs may not be easily satisfiable. Depending on their needs and thus their culture, the agents will adapt their behavior, some agents will stay in quarantine for the required amount of time, others will sneak out and go shopping (satisfy luxury) or meet friends (satisfy belonging).

3.4 Objectives

The objective for an agent is to get a high quality of life. The quality of life is defined as the weighted average of the need satisfaction. Thus when the agent is able to satisfy all the needs (full tanks) it has a high quality of life. The agent has to get itself into situations where it can satisfy its needs, so for example it needs some money to be able to buy and shop (food safety or self-esteem needs). To assess the whole population the averages of the needs are shown in the interface.

3.5 Learning

There is no form of learning modelled in the agents.

3.6 Prediction

The agents have a form of prediction. When confronted with having to choose an action (on a new time of the day) the agent will predict which action will give it the best satisfaction for its needs.

3.7 Sensing

The agents are aware of where they are and at which type of activity, the time of the day and why they are at the activity (their motivation). The agents also know about the activities of their social network and actually go to private leisure with their friend group. The agents also have a family and colleagues.

The agents are aware of their disease, when they get symptoms they believe they are sick. However due to the epistemic model an agent can sometimes be sick but not believe it is sick, or the opposite. The same goes for immunity.

3.8 Interaction

The interactions consist of agents being together at the same gathering point. This has two consequences for the agents 1) the needs are influenced and 2) the disease can be spread. Spreading the disease happens with a certain probability when one agent is infectious and the other agents do not have the disease and are not immune. When there are more infected people the probability increases. The agents also have interaction with the places, at a shop the agent can buy food at a workplace the agent can work. There is no possibility for an agent to do direct actions against other people.

3.9 Stochasticity

The initialization of the needs for the agents is stochastic as the needs vary slightly among agents based on a random chance. The needs model itself is not stochastic as for action selection it takes the action that has the highest need satisfaction.

The spread of the disease is stochastically determined, people in the same gathering point have a chance of infecting each other based on the density of the gathering points and the infectiousness of the infected person. The disease model has stochastic elements such as the severity of the disease, the survival chance, and the length of being in a specific disease state. The epistemic state is influenced by chance to occasionally create false beliefs in the agents.

3.10 Collectives

The collectives in the game are social networks. There are social networks, based on relatives and friends. There is also a work network based on people that go to the same office gathering point.

3.11 Observation

Since the model has so many elements, we also have a large set of output values (more than 100). The most prominent are the amount of infected, the amount of people believing they are infected, fatal cases, number of tests performed, R0, the number of people infected by others per age, and the number of contacts people had. There are many more of interest such as data pertaining to the needs model and the economical model. However the specific variables of interest are very dependent on what scenario is analyzed. The full list of scenarios can be found in Appendix B.

4 Initialization

Statistical data is used to initialize the age of the agents and the household settings. Furthermore divorced parents with children and multi generational living will be taken into account. In total 300 agents or 1000 agents will be spawned in the simulation (the exact amount is dependent on the number of households). They get a social network and assigned gathering places after spawning. The distribution of the environmental aspects such as restaurants, offices, schools, and so forth is done by design.

The scenarios have specific starting parameters and structures (Appendix B). In the Netlogo implementation it is easy to set the starting parameters according to the desired scenarios. Selecting the desired scenario in the *preset-scenario* list and press *load scenario-specific parameter settings*.

5 Input

As mentioned before, statistical input is used to set-up household settings and age. The disease model is based on the Oxford model. The other input settings were manually selected. The Interventions and policies to be used can be selected manually to observe their effect on the COVID-19 simulation. 171 input variables, around 170.

6 Appendices

6.1 Appendix A - Disease Model (Oxford)

This process is shown in the figure below from the Oxford model.

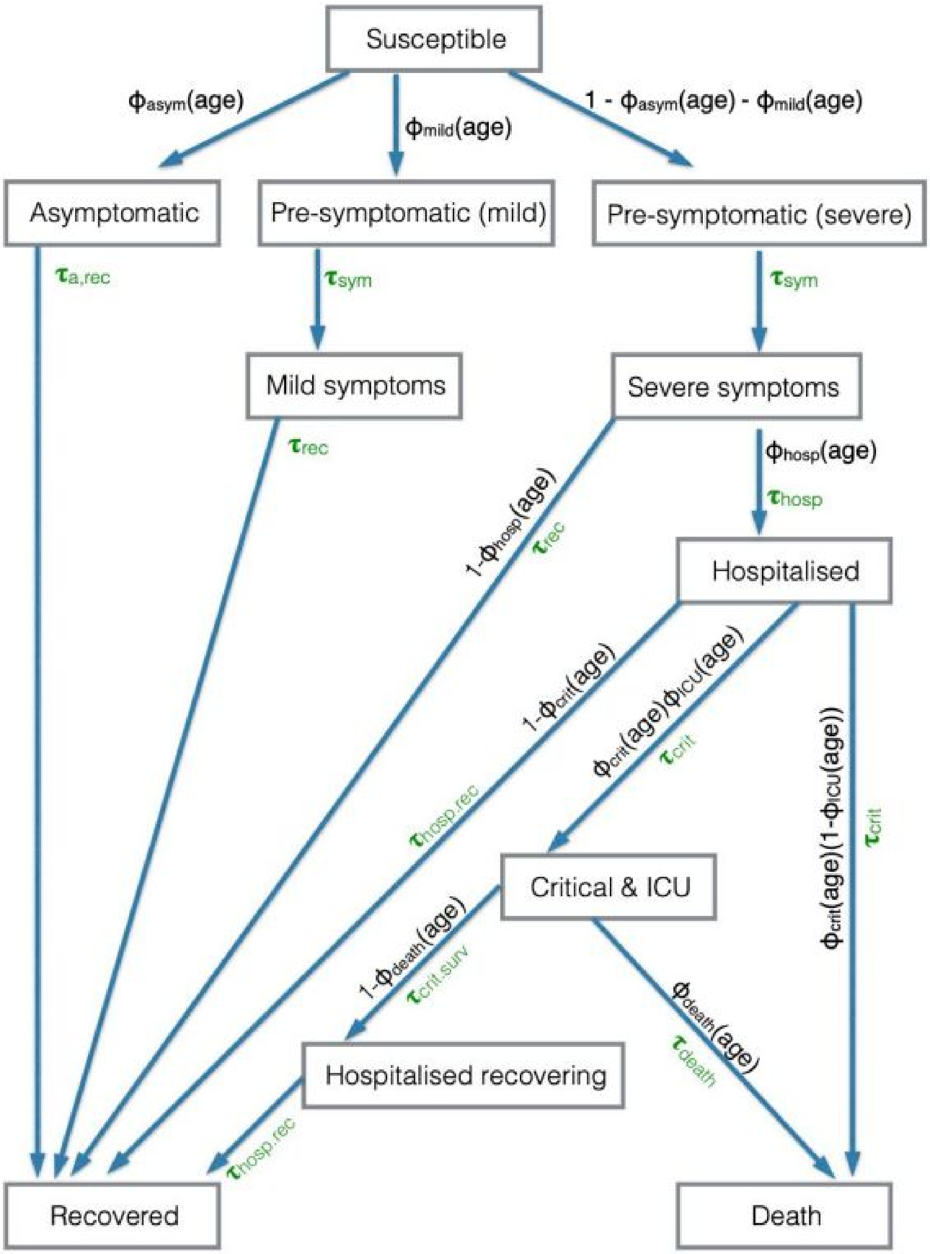

Figure: This is the figure from the Oxford disease model, supplementary Figure 1 in *Hinch R. et al. 2020 - Effective Configurations of a Digital Contact Tracing App: A report to NHSX*

The parameter settings for the disease model are taken from the oxford model as well. They can be found in the *Parameters_baseline.csv* in the following github link https://github.com/BDI-pathogens/OpenABM-Covid19/tree/master/documentation

6.2 Appendix B - Scenarios

In order to investigate the effect of different interventions and other possible factors on the course of the COVID-19 disease, different scenarios have been created. This is a growing list and more scenarios will be added in the future. The current scenarios are as follows:

- Closing schools
  - See Supplement scenario - Closing of schools
- Testing on corona to reduce spread
  - See Supplement scenario - Testing on corona to reduce spread
- Economic effects
  - See Supplement scenario - The economy
- Tracking app
  - See Supplement scenario - Comparison with mathematical model
- Smart testing
  - See Supplement scenario - Smart testing
- Phasing out and exit strategies
  - See Supplement scenario - Phasing out strategies

6.3 Appendix C - List of other supplements

Supplement 1 - The conceptual cultural model

Supplement 2 - Household composition

Supplement 3 - Needs (when it is there)

Supplement 4 - Social Networks

Supplement 5 - Economy for Covid-19 ABM

Supplement 6 - Transport model