



Covid-19 Spread Simulation tool for Africa

Documentation

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Context

The COVID-19 outbreak was declared a Public Health Emergency of International Concern by WHO on 30th January 2020. At that time, African countries were less affected. Since then, the global COVID-19 situation is rapidly changing, almost all African countries have recorded COVID-19 cases, some like with a rapid spread. It appears the evolution of the pandemic in Africa has been slow where the caseload has been significantly lower than any other continents. With a big promotion of African countries reporting imported cases and local transmission, it is not clear in what direction the pandemic will take in Africa. In addition, different African countries have mounted different intervention, some applied largely in haphazard approach on one hand, but not routinely evaluated to ascertain their efficacy and how they impact on the overall economic fabric of these Member States. No country in the world seems to have been well prepared to face the COVID-19 and the understanding of the disease spread mechanisms and the impact of various public health interventions to slow down its progress is still low, especially in environmental and socio-economic conditions prevailing on the African continent.

Introduction

The tool is designed to enable a user to simulate different Covid-19 spread scenarios for each african country, over 300 days, based on their actual reported cases and observe the impact of different NPI policies.

The tool and its set of default parameters delivered by The Synergist to ARC shall not be considered as the reference values of any kind. The adjustment of the parameters is up to ARC to conduct.

The tool is made of 5 functional components:

1. A heatmap of Africa with the main KPIs of the Covid-19 spread visible for all countries
2. A web interface to interact with the model and visualize results
3. An integration with external databases for updating the actual cases reported by the countries: [Worldometer.org for current situation](https://www.worldometers.info/coronavirus/), [JHU databases on Github for time-series](https://github.com/CSSEGISandData/COVID-19).
4. An internal country static data file for population, level-1 administrative unit, percentage of vulnerable population, fluxes of people between level-1 administrative units.
5. An epidemiological compartmental model to simulate the spread of the model
6. A NPI policy simulator translating user input into values for the compartmental model. The NPI simulator also considers socio-economic measures for their influence on lockdown measures in particular for the most vulnerable populations unable to afford a complete lockdown.

Delivery

The deliverables to ARC are the following:

1. The source code, delivered through access to the private Github repositories to a designated user of ARC. Note that an account with Github is necessary.
 - a. <https://github.com/Rubyx-IO/ModellingCovid19Africa> for the compartmental model
 - b. <https://github.com/Rubyx-IO/VizualizingCovid19Africa> for the front end
 - c. <https://github.com/Rubyx-IO/RWebServiceCovid19Africa> for the NPI policy simulator
 - d. <https://github.com/Rubyx-IO/AWSInfraCovid19Africa> for the AWS infrastructure as a code
2. The installation of the tool on ARC's Amazon Web Services account
3. This document provides the necessary information to understand and use the tool.

User flow

Baseline Model initialisation

Step 1

Once a country is chosen, the orchestrator will retrieve the country data:

- Administrative units (Gaul-1)
- Population
- Migration fluxes inside the country
- % of vulnerable people

Step 2

The model initiates the country's "communities" at two levels

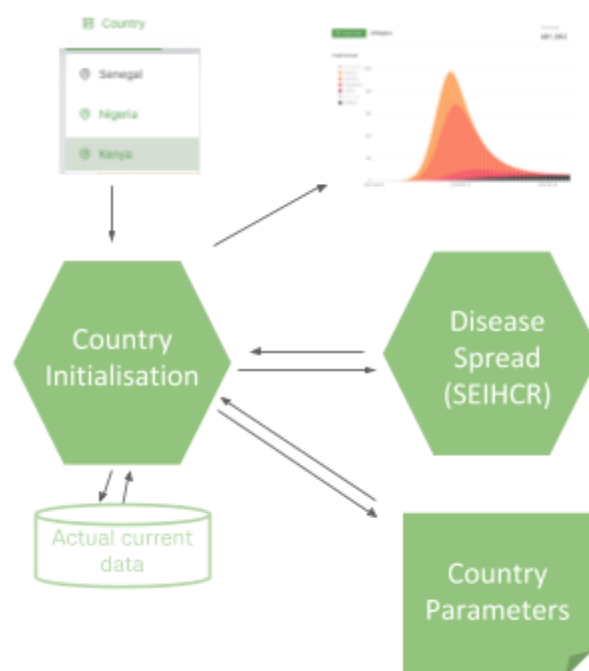
1. Admin unit
2. Vulnerable / Standard

Step 3

Then, the historical data (time series) will be retrieved from John Hopkins University database and the current situation will be retrieved from the Worldometer.

Step 4

The country will then be initialised by distributing the cases into the communities and the disease stages: Susceptible, Exposed, Infectious, Hospitalised, Critical (care), Recovered, Fatalities



Step 5

The spread model SEIHCR will then simulate over time how people move from one compartment of the disease to another.

Defining an NPI Policy

Step 1

A full NPI policy is defined by the user including socio economic measures.

Step 2

The NPI model will convert the policy in parameters for the spread model and breakpoints to indicate when measures change.

Step 3

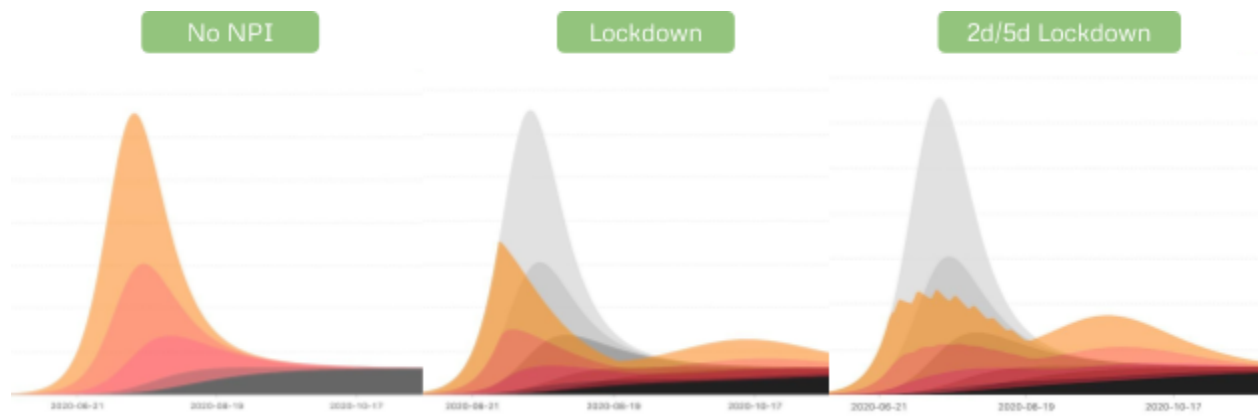
The spread model will run a second time with breakpoints. At each breakpoint the main parameters can be altered with factors.

Step 4

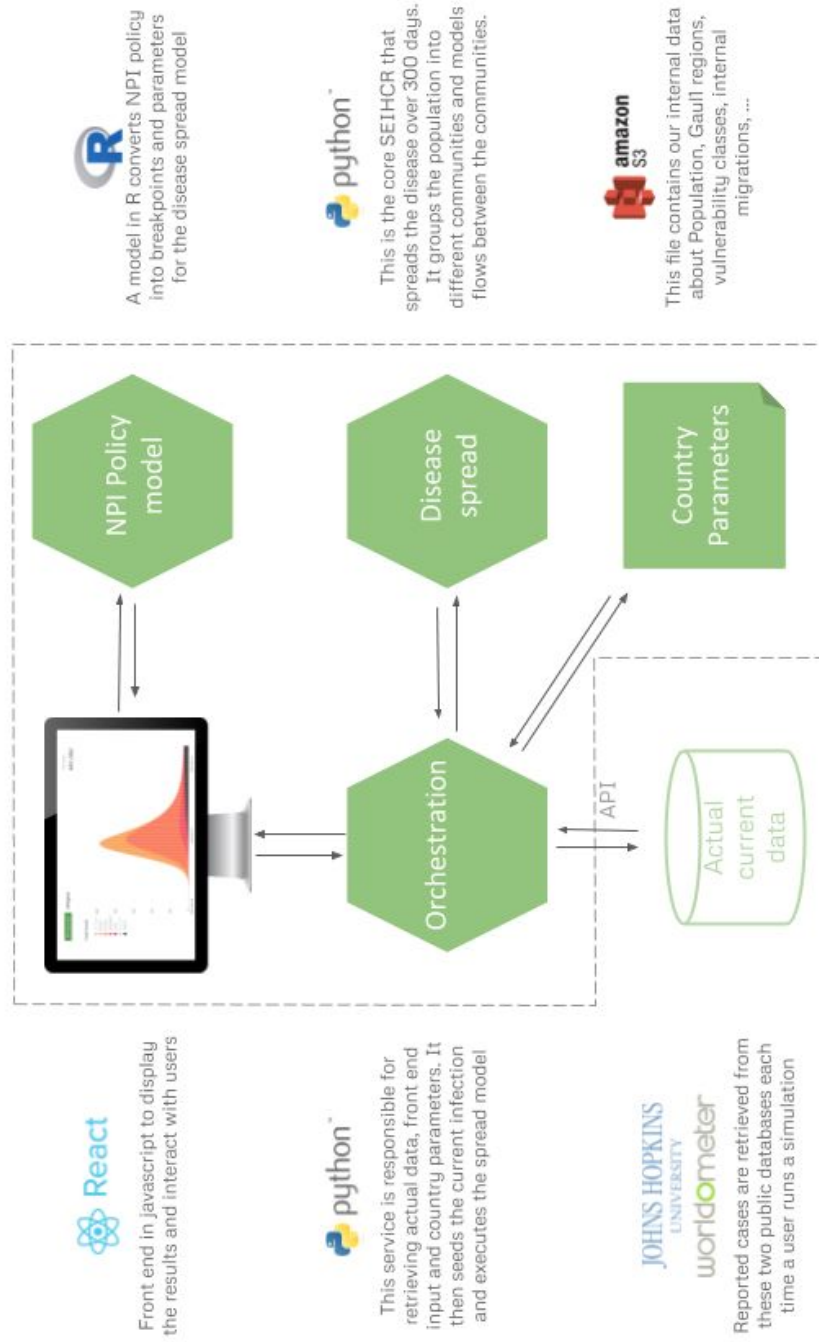
Both results are shown on screen, with a without NPIs for comparison.



Example of NPI policies effects visualization on the disease spread



Architecture



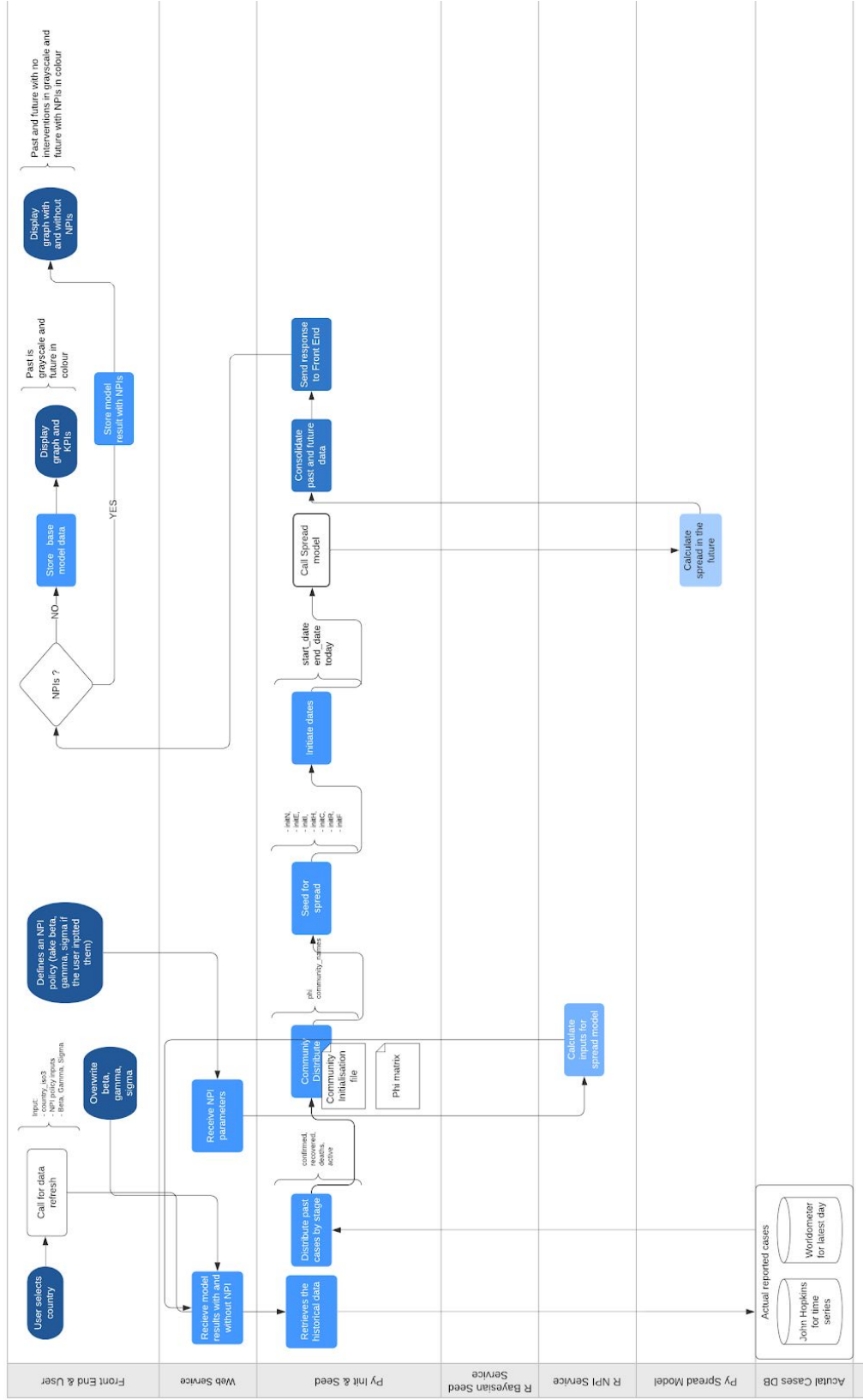
Orchestration

The role of the orchestrator ([country_data.py](#)) is to:

- Fetch the historical data of the country, via Johns Hopkins University [github repository](#)
- Fetch latest data of the country, from [Worldometers](#), via Python package Covid
- Get the flux matrix split into adm1 sub-national levels
- Split the flux matrix into vulnerable sub-populations
- Get the standard values for beta, gamm, sigma (or the ones provided by the user)
- Launch the simulation with migration (using the constructed flux matrix), with and/or without NPI. This creates a reference model (no NPI) and/or a model run with NPI
- Return the results to the Front End, as JSON

NB:

- the JSON returned to the Front End contains:
 - A dictionary of the communities, divided into:
 - Vulnerable: vulnerable population
 - Standard: standard population
 - All: aggregate
 - A dictionary “All” of the aggregate communities, divided into:
 - Vulnerable: vulnerable population (national level)
 - Standard: standard population (national level)
 - All: aggregate (national level)
- All the communities defined above contain a dictionary of:
 - S: time-series of the susceptible population
 - E: time-series of the exposed population
 - I: time-series of the infectious population
 - H: time-series of the hospitalised population
 - C: time-series of the critical population
 - R: time-series of the recovered population
 - F: time-series of the fatal population
 - Rt: time-series of the Reproduction number
 - Kpi: a dictionary of kpis, such as the total number of deaths, the peak icu date,
...



SEIHCRF Model Input Parameters

Model Initialization

This step is seeding the compartments with initial values and providing the main disease spread parameters.

Field Name	Description	Data Type	Default
Model Initialization			
beta	Rate of transmission (exposure)	Float or sequence of floats $\beta \in]0, 5[$	0.896 Can be set at admin 1 level Is overwritten at country level by the user input
sigma	Rate of infection (upon exposure)	Float or sequence of floats $\sigma \in]0, 1[$	0.344 Can be set at admin 1 level Is overwritten at country level by the user input
gamma	Rate of recovery (upon infection)	Float or sequence of floats $\gamma \in]0, 1[$	0.192 Can be set at admin 1 level Is overwritten at country level by the user input
initN	Init number of individuals	Float (int) or sequence of floats (ints)	From the admin 1 level population
initE	Init number of exposed individuals	Float (int) or sequence of floats (ints)	0
initI	Init number of infectious individuals	Float (int) or sequence of floats (ints)	Active cases retrieved from worldometer.org
initH	Init number of hospitalized individuals	Float (int) or sequence of floats (ints)	0
initC	Init number of critical individuals	Float (int) or sequence of floats (ints)	Critical cases from worldometer.org
initR	Init number of recovered individuals	Float (int) or sequence of floats (ints)	Recovered cases from worldometer.org
initF	Init number of infection-related fatalities (all remaining nodes initialized susceptible)	Float (int) or sequence of floats (ints)	Deaths from worldometer.org

m	Fraction of infectious that are asymptomatic or mild	Float	0.85
c	Fraction of severe cases that turn critical	Float	1./3.
f	Fraction of critical cases that are fatal	Float	0.5
t_h	Time a sick person recovers or deteriorates into a critical state	Float	11.5
t_c	Time a person remains critical before dying or stabilizing	Float	13.

Model Run

The model run parameters define how the compartment model is executed.

Model Run			
T	the number of epochs to run it for, in days	Int or Float	300.
dt	timestep	Float	1./24.
checkpoints	For params that don't have given checkpoint values (or bad value given), set their checkpoint values to the value they have now for all checkpoints.	Dictionary 't': list of ints or floats 'beta_factor': float or list of floats 'sigma_factor': float or list of floats 'gamma_factor': float or list of floats	
migration_in_out	Time for migration in and out	List of 2 floats	[8./24., 16./24.]

Checkpoints

The checkpoints allow to define dates at which the disease spread model parameters change. The NPI Policy Simulator will be defining the checkpoints according to the dates inputted by the user in the NPI policy. At each checkpoint, initial parameters are altered by a factor. The

number of possible checkpoint per day is determined by the value of the parameter dt explained in the section [Model Run](#) above.

Checkpoints			
t	Days to change parameters	List of ints OR floats	
beta_factor	Rate of transmission (exposure)	List of floats OR list of list of floats	
sigma_factor	Rate of infection (upon exposure)	List of floats OR list of list of floats	
gamma_factor	Rate of recovery (upon infection)	List of floats OR list of list of floats	
phi_factor	Factor to multiply phi (migration fluxes)	Scalar, vector or matrix	
repeat	Repeating patterns	Dict: { 'time_scale': list of floats, 'breakpoints': list of list of 2 floats }	

When providing checkpoints, only the factors that change need to be passed, the others will be inferred from their initial (or last) value.

At each checkpoint time, the parameters passed can either be a float (national level) or a list of floats (community level).

phi_factors can be 0D, 1D or 2D arrays (scalar, vector or matrix)

- A scalar will multiply all the fluxes at national level
- A vector will multiply all the fluxes at community level
- A matrix will multiply all the fluxes at inter-community level

Examples Checkpoints

Let's take Burkina Faso (13 adm1 entities) with NPI applied between day 50 and 100 from simulation start:

A community-level reduction is applied (list of 13 factors), then a national reduction (1 factor)

checkpoints = {

 't' : [50, 100],

 'beta_factor' : [[0.75, ..., 0.33], 0.15]

```
}
```

Vulnerable communities are implemented ($13 * 2 = 26$). Vulnerable communities have a factor of 0.8, whilst standard communities have a factor of 0.3. A vulnerable-community level reduction is applied (list of 13 repeating pairs = 26 factors), then a national reduction (1 factor)

Example Checkpoints with repetition

2d/5d for 4 months, then introducing school closure after 1 month for the remaining 5 months

```
checkpoints = {'t':      [[0, 120], [120, 270]],  
              'beta_factor': [[0.66, 0.5], [0.5, 1.]],  
              'repeat': {'time_scale': [7., 5*30.], 'breakpoints': [[0., 2.],[0., 5.*30.]]}  
              }
```

Country parameters

Countries are initialised with external data from [Worldometer.org for current situation](#), [JHU databases on Github for time-series](#).

In addition, the source of the tool contains a country initialisation file to be found here: https://github.com/Rubyx-IO/ModellingCovid19Africa/blob/bertrand_communities_SEIHCRF/python/data/countries/Community_initialisationA.csv. It contains the following fields for each community. The community is either the vulnerable or standard population of a level 1 administrative unit.

- Country_Code
- adm1_name
- adm1_code
- pop_sum
- beta
- gamma
- sigma

In addition, the tool has matrices of fluxes of people between regions within a country. This is also used as parameters and can be adjusted with more accurate data when available. Example of such a matrix used for Djibouti. This is the percentage of people moving from one admin unit to another.

All matrices can be found in the source repository under the following link: https://github.com/Rubyx-IO/ModellingCovid19Africa/tree/bertrand_communities_SEIHCRF/python/data/migration/Phi%20SV

Q Search this file...

		609	610	611	612	613	614	615	616	617	618	619	620
1													
2	609	0	0.001109	2e-04	0.002303	0.000408	0.00018	0.000471	5.9e-05	5.2e-05	0.00022	0.000201	0.000364
3	610	0.000795	0	0.000202	0.002917	0.000348	0.000191	0.004051	5e-05	8.6e-05	0.000115	0.000134	0.000311
4	611	0.000148	0.000153	0	0.000322	0.000255	0.000477	0.000174	0.00292	0.00059	0.002529	0.000577	0.00042
5	612	0.001286	0.002134	0.000276	0	0.000564	0.000248	0.002963	8.1e-05	7.2e-05	0.000304	0.000277	0.000503
6	613	6.8e-05	7e-05	0.000471	0.000174	0	0.000775	0.000381	6.2e-05	0.000242	0.000221	0.001291	0.005585
7	614	7.2e-05	7.4e-05	0.001454	0.000156	0.000124	0	8.5e-05	0.000298	0.004028	0.000293	0.00023	0.002491
8	615	0.000366	0.005949	0.000138	0.001987	0.000413	0.00013	0	3.4e-05	5.8e-05	7.9e-05	9.1e-05	0.000212
9	616	6.1e-05	6.3e-05	0.00708	0.000133	0.000105	0.000197	7.2e-05	0	0.000243	0.001043	0.000238	0.000173
10	617	4.9e-05	5e-05	0.002222	0.000105	8.3e-05	0.005972	5.7e-05	0.000335	0	0.000255	9.8e-05	0.000305
11	618	0.000116	0.00012	0.002983	0.000253	2e-04	0.000268	0.000137	0.003445	0.000331	0	0.000585	0.000437
12	619	6.4e-05	6.6e-05	0.000856	0.000138	0.00011	0.000176	7.5e-05	0.000198	9.5e-05	0.006459	0	0.001146
13	620	8.6e-05	8.9e-05	0.001556	0.000187	0.000148	0.004549	0.000101	0.000165	0.00027	0.000448	0.001567	0

Disease Spread Model

The disease spread model is based on the family of compartmental epidemiological SIR models. At each time t , every individual of the population belongs to one of these compartments:

- S: susceptible, population that has not been infected
- E: exposed, population that has been exposed to the virus, but is still not infectious
- I: infectious, population that is infectious and can infect the susceptible population
- H: hospitalised, population that requires hospitalisation
- C: critical, population that requires to be treated in ICU (Intensive Care Unit)
- F: fatal, population that has died
- R: recovered, population that has recovered

Individuals transit from one compartment to another with the rates β , σ , γ . The reproduction number R is given as the ratio between β and γ , the time of infectiousness is given as the inverse of γ , and the time of incubation is given as the inverse of σ .

Communities

The disease spread model consists of differential equations that rule the population's transitions between compartments that represent different stages of the disease (susceptible, exposed, infectious, hospitalised, critical, fatal and recovered).

The current model implements the generic abstract concept of *communities*.

- Each community represents a sub-population that has its own system of epidemiological differential equations.
- The flux matrix represents the interaction between the different communities
- Communities are abstract and generic, it can represent:
 - Geographical sub-national entities
 - Vulnerable split of the population
 - Age category
 - A combination of multiple splits (e.g. geographical + vulnerable + age)
 - ...

So the concept of community can literally encompass anything, as long as the flux matrix ϕ representing the fluxes of interaction between communities are consistent. Note that for this project, the community concept has been used for two purposes:

- Vulnerability
- Level 1 Administrative units (GAUL-1)

Examples

1. Splitting Africa into communities representing the different countries, and the fluxes between them
2. Splitting a country based on rural/urban division
3. Splitting a country based on age distribution
4. Splitting a country based on access to water, sanitation, and hospital needs
5. Splitting a country based on climate variations
6. ...

Fluxes

The flux matrix ϕ is originally based on geographical migration but can be adapted to any kind of community. The coefficient ϕ_{ij} represents the proportion of community i that enters in contact with community j .

For instance, to split communities based on age distribution, one could imagine splits such that

- Community “Young”: [0-16]
- Community “Working adults”: [16-50]
- Community “Elderly”: [50+]

In this example, the ϕ matrix (3x3) should represent the intergenerational interactions between communities. For instance, a fraction of the working adults interacts with their kids, a fraction of the kids interact with their grandparents, ...

By fine tuning the ϕ coefficient, one can implement different rules of social distancing and other measures per community, affecting directly the way the disease spreads within that

community. For instance, if it appears that the elderly are more impacted by the disease, it can be worth imagining a stronger social distancing measure for that community whilst giving the working adults community a bit more freedom to keep the economy afloat.

Model Output

Field Name	Description	Data Type	Example
Model Results			
All	Sum of all communities	Series Object	
Community_i	Community level results	Series Object	
Series Object			
F	Fatality	List of ints	
E	Exposed	List of ints	
C	Critical	List of ints	
H	Hospitalised	List of ints	
I	Infectious	List of ints	
R	Recovered	List of ints	
S	Susceptible	List of ints	
Rt	Reproduction Rate Time Series	List of float	(Not in All)
R0	Reproduction Rate	Float	(Not in All)
kpi		KPI Object	
KPI Object			
total_F	Total Death		
d_herd_immunity	day when the herd immunity is reached		
d_peak_h	day when the hospitalised peak		
d_peak_c	day when ICU peak		
peak_h	hospitalisation peak (number of)		
peak_c	critical (icu) peak (number of)		

peak_daily_h	peak of daily (new) hospitalisations (number of)		
peak_daily_f	peak of daily (new) deaths (number of)		
d_peak_daily_h	day when the daily hospitalisations is the highest		
d_peak_daily_f	day when the daily fatalities is the highest		

NPI Policies

The disease spread model, as presented in the previous section, is a general algorithm whose dynamics are determined by its input parameters. In absence of interventions, these parameters are determined by biological and demographical mechanisms¹. However, governments can slow down the spread of COVID-19 through Non Pharmaceutical Interventions (NPIs). In the Disease Spread Model it means that NPIs impact at least some of its input parameters. This section explains how NPIs are translated into factors (numbers) that change (multiply) some of the initial input parameters of the model.

On the front-end, the user is able to specify a *NPI strategy*, i.e. a set of NPI policies and their implementation over time. Under the button **Define NPIs** the user opens a screen where several NPIs can be switched on/off, and defines the start and end date of each NPI and the intensity of the measure when applicable. Different NPIs have different impacts in different parameters of the disease spread model. The available NPIs impact either *beta* (used in the computation of the reproduction number R) OR the *phi* matrix that encompasses the information on the fluxes (contacts) between the communities (in the generic sense discussed in the previous section). The *phi* matrix can be impacted in 2 different ways: (i) inter-regional fluxes and (ii) inter-vulnerability groups fluxes.

The available NPIs are described below.

NPIs

Available NPIs are grouped into 4 categories:

- City level: NPIs that establishes what services are shut down;
- Stay at home: NPIs that aim at increasing social distancing through the decrease of people circulating around the city;
- Geo-fluxes: NPIs that aim at decreasing the spread of the virus between different geographical regions;

¹ Scientific teams from around the globe are putting substantial efforts on the estimation of such parameters, but virtually no estimates are available for Africa and even in regions where estimates have been produced, their degree of uncertainty remains substantially high.

- Socio-economic: NPIs that, by relaxing binding constraints on survival revenues, increases the social compliance to the other NPIs.

City level

- Public gatherings: concerts, matches, etc are forbidden;
 - User inputs: Start and End dates;
 - Impact: decrease on ***beta***;
 - Reactive to cash-transfers: no;
- Schools: schools and universities are closed;
 - User inputs: Start and End dates;
 - Impact: decrease on ***beta***;
 - Reactive to cash-transfers: no;
- Markets: main markets and shops are compelled to close;
 - User inputs: Start and End dates and intensity level (1 or 2);
 - Impact: decrease on ***beta***;
 - Reactive to cash-transfers: no.

Stay at home

- Official statements: the population is aware of the importance of social distancing;
 - User inputs: Start and End dates;
 - Impact: decrease on ***beta*** and decrease of inter-vulnerability fluxes on the ***phi*** matrix;
 - Reactive to cash-transfers: yes;
- Curfews: hours or weekdays where going out is forbidden;
 - User inputs: Start and End dates, Days of the week where curfew applies and hours of the day where the curfew applies;
 - Impact: decrease on ***beta*** and decrease of inter-vulnerability fluxes on the ***phi*** matrix, both identical to the lockdown decrease during the curfew periods (days and hours) and identical to official statements during the non curfew periods (but policy in place);
 - Reactive to cash-transfers: yes;
- Lockdown: it is forbidden to go out but for 'survival' reasons;
 - User inputs: Start and End dates;
 - Impact: decrease on ***beta*** and decrease of inter-vulnerability fluxes on the ***phi*** matrix;
 - Reactive to cash-transfers: yes;

Geo-fluxes

- Official statements: importance of staying in the geographical area;
 - User inputs: Start and End dates;
 - Impact: decrease of inter-regional fluxes on the ***phi*** matrix;
 - Reactive to cash-transfers: yes;

- **Curfews:** hours or weekdays where geo-fluxes are forbidden;
 - User inputs: Start and End dates and Days of the week where curfew applies;
 - Impact: decrease of inter-regional fluxes on the **phi** matrix, identical to the lockdown decrease during the curfew periods (days of the week) and identical to official statements during the non curfew periods (but policy in place);
 - Reactive to cash-transfers: yes;
- **Lockdown:** geo-fluxes are forbidden if not essential;
 - User inputs: Start and End dates;
 - Impact: decrease of inter-regional fluxes on the **phi** matrix;
 - Reactive to cash-transfers: yes;

Socio-economic enabling measures

- **Cash-transfers:** vulnerable socio-economic groups get monthly transfers;
 - User inputs: Start and End dates, percentage of the population benefiting from the transfers, amount transferred by family and month;
 - Impact: increased compliance to all NPIs.
- **Bills on hold:** payments of utility bills, mortgages and loans are on hold;
 - User inputs: Start and End dates and intensity level (1, 2 or 3);
 - Impact: increased compliance to all NPIs.

NPI's impact mechanisms

The activation of each NPI is associated with a multiplicative factor that will impact one or two input parameters of the disease spread model (cfr. above).

The decrease on **beta** is generated by a *stay at home* measure (the most binding) in combination with all the city level measures:

$$F_{\beta, c} = f_{\beta, c, \text{stayhome}} * f_{\beta, c, \text{gather}} * f_{\beta, c, \text{school}} * f_{\beta, c, \text{markets}}$$

That reads: the initial **beta** parameter for community *c*, will be multiplied by $F_{\beta, c}$ (Beta Factor) that is composed by (i) $f_{\beta, c, \text{stayhome}}$ the impact of the most binding stay at home measure (between 0 and 1), (ii) $f_{\beta, c, \text{gather}}$, the impact of forbidding public gatherings (between 0 and 1), (iii) $f_{\beta, c, \text{school}}$ the impact of closing schools and universities (between 0 and 1) and (iv) $f_{\beta, c, \text{markets}}$ the impact of closing public markets (between 0 and 1).

The decrease in fluxes between vulnerability groups (communities) and the decrease in inter-regional fluxes, through changes in the **phi** matrix, are generated by the most binding *stay at home* measure and *geo-fluxes* measure respectively. They are expressed by $F_{\phi, c1, c2}$ and $F_{\phi, c1, c2}$ both factors between 0 and 1 that multiplies the part of the flux matrix that corresponds to the fluxes between communities *c1* and *c2*.

Each multiplicative factor is composed by 2 components: its maximum potential effectiveness and a loss of effectiveness specific to either the vulnerable or non-vulnerable community. These parameters and their default values in the delivery to ARC are summarized in the table below:

NPI	F _{max effect}	F _{Vulnerable loss}	F _{Non Vulnerable, loss}	F _{Vulnerable}	F _{NonVulnerable}
Public gatherings	0.8	0.15	0.05	0.95	0.85
Schools closed	0.6	0.3	0.1	0.9	0.7
Markets closed	0.6	0.3	0.1	0.9	0.7
Home Pub. statement (beta)	0.6	0.3	0.1	0.9	0.7
Home Pub. statement . (phi)	0.6	0.3	0.1	0.9	0.7
Home Lockdown (beta)	0.1	0.4	0.2	0.5	0.3
Home Lockdown (phi)	0.1	0.4	0.2	0.5	0.3
Geo Public statement	0.6	0.3	0.1	0.9	0.7
Geo Lockdown	0.1	0.4	0.2	0.5	0.3

In absence of cash transfers (socio-economic measure), assuming the values in the table above, a Home Lockdown would multiply the parameter **beta** in the disease spread model by 0.5 (0.1+0.4) among the vulnerable community and by 0.3 (0.1+0.2) among the non-vulnerable community. The difference is due to the fact that vulnerable populations have more binding cash constraints for survival and are less likely to respect the NPI in place. However, this constraint can be lifted by cash-transfers through the mechanism described in the next subsection.

Socio-economic measures

The major specificity of the way NPIs are simulated within this tool, and what gives it a particular pertinence for the African continent, is the fact that each NPI has a potential maximum impact (compliance level) that can only be achieved if it is accompanied by cash-transfers that lift survival constraints weighting over the most vulnerable. Cash-transfer measures are determined by (i) their start and end dates, (ii) the amount to be transferred to each beneficiary family and (iii) the proportion of the population that is covered by the measure.

In addition, the poverty line is set at 2 USD/day/capita, the average family size is set at 5 household members and the purchasing power parity at 1². They are used to compute the poverty monthly revenue for each family. The idea is that the higher are the cash transfers

² These parameters could be set in accordance to the standards of each country.

and the more vulnerable households will comply with the NPIs. This relationship is characterized by the fact that when a vulnerable household receives a cash transfer that corresponds to the monthly poverty revenue, it will as likely to comply with the NPIs in place as a non-vulnerable household. Moreover, only a proportion of vulnerable households will benefit from such transfers. The resulting equation:

$$f_{beta,vul} = p_{ct} \left(f_{beta,max\ effect} + \frac{f_{beta,vul\ loss}}{1 + \alpha_{beta,vul} * V} \right) + (1 - p_{ct}) \left(f_{beta,max\ effect} + f_{beta,vul\ loss} \right)$$

with:

$$\alpha_{beta,vul} = \frac{f_{beta,vul\ loss}}{PR * f_{beta,non\ vul\ loss}} - \frac{1}{PR}$$

where:

$f_{beta,vul}$: is the impact of a given NPI on **beta** among the vulnerable community *vul*;

$f_{beta,max\ effect}$: is the maximum potential effectiveness on **beta** of the same NPI;

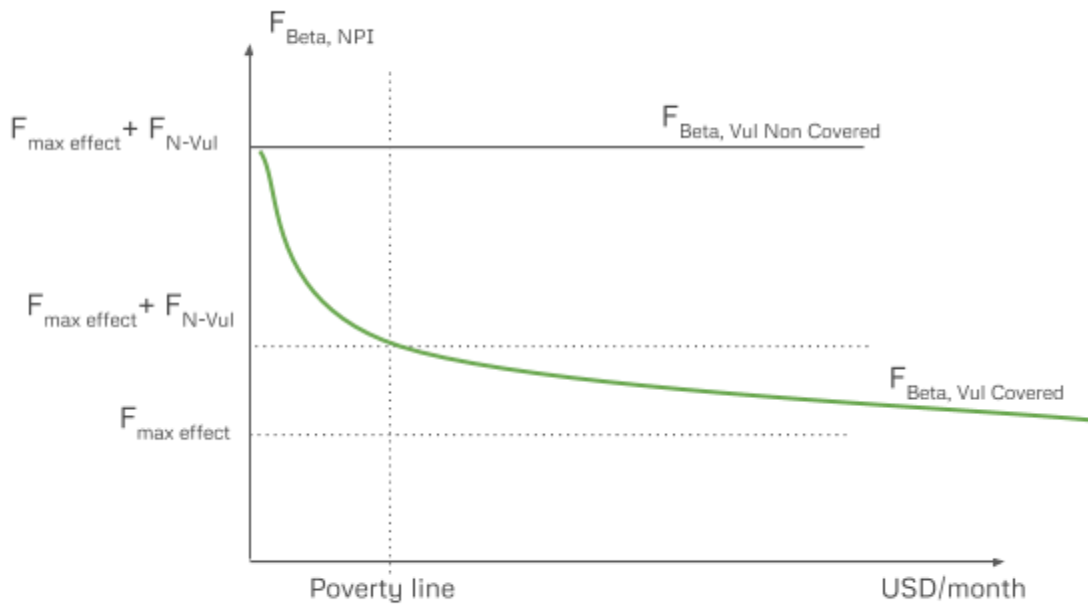
$f_{beta,vul\ loss}$: is the loss of effectiveness among the vulnerable community;

$f_{beta,non\ vul\ loss}$: is the loss of effectiveness among the non vulnerable community;

p_{ct} : is the proportion of the vulnerable population who benefited from the cash-transferts;

V : is the amount (USD) transferred by month to each household;

PR : is the monthly revenue a typical household should get in order to reach out the poverty.



NPI Policy Simulator input parameters

Field Name	Description	Data Type	Example
country	Country's name	String	ISO, 3 digits
Intervention			
geo_stay	If the user chooses to apply this measure: Stay in your area	Boolean	True / false / undefined
geo_stay_date		Date Range	["2020-04-11","2020-05-08"] ["2020-04-11",null] [null, null] Values can be none
geo_lockdown		Boolean	
geo_lockdown_date		Date Range	
geo_curfew		Boolean	
geo_curfew_date		Date Range	
geo_curfew_weekdays		List of Weekdays	[1, 2, 3] 1. Monday 2. Tuesday 3. Wednesday ...
home_stay	Stay at home	Boolean	
home_stay_date		Date Range	
home_lockdown		Boolean	
home_lockdown_date		Date Range	
home_curfew		Boolean	
home_curfew_date		Date Range	
home_curfew_hours		Time Range	
home_curfew_weekdays			

city_forbid	Forbid public gatherings	Boolean	
city_forbid_date		Date Range	
city_close_school		Boolean	
city_close_school_date		Date Range	
city_close_market		Boolean	
city_close_market_date		Date Range	
city_close_market_selection		Number	<ol style="list-style-type: none"> 1. Main public markets 2. All shops except pharmacy and grocery stores
socio_transfer	Subsistence transfers	Boolean	
socio_transfer_date		Date Range	
socio_transfer_population		Number	60: means 60%
socio_transfer_amount_usd		Number	
socio_freezing	Bill freezing	Boolean	
socio_freezing_date		Date Range	
socio_freezing_level		Number	1 / 2 / 3 <ol style="list-style-type: none"> 1. Utilities 2. Utilities and rent 3. Utilities, rent and loan repayment

NPI Policy Simulator output parameters

Field Name	Description	Data Type	Example
initN	[required] Init number of individuals		
beta	[required] Rate of transmission (exposure)		
sigma	[required] Rate of infection (upon exposure)		

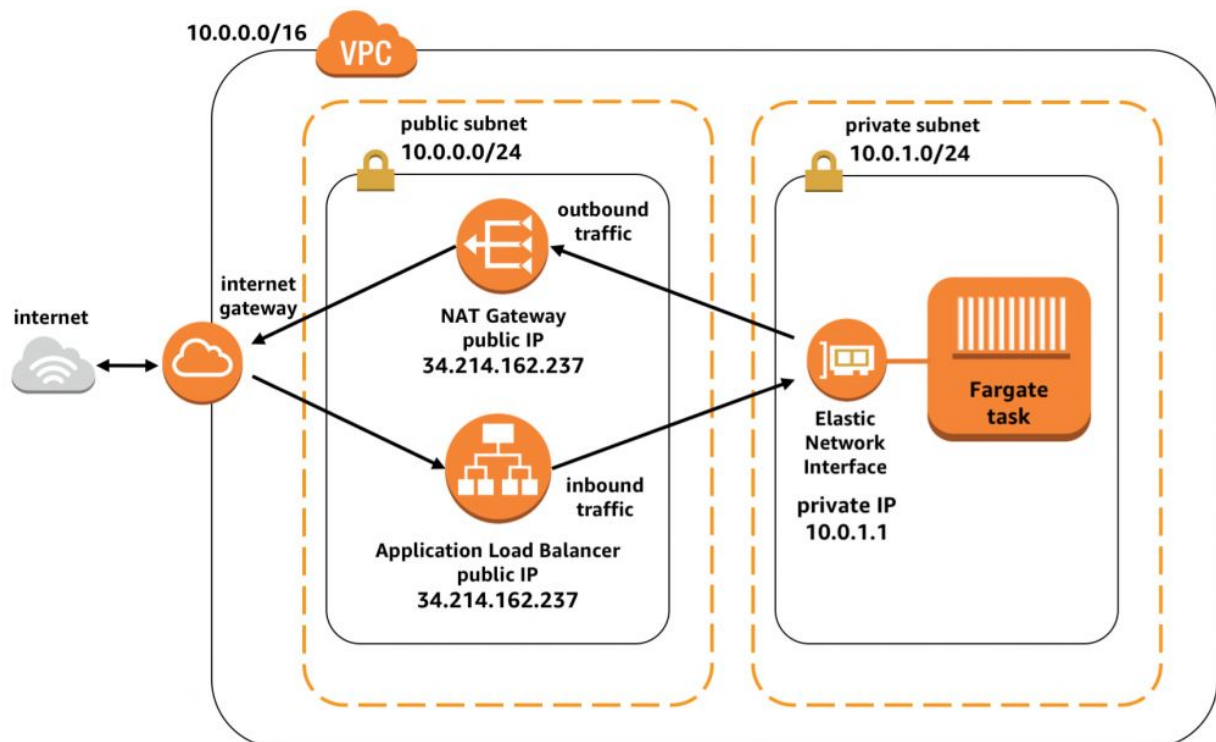
gamma	[required] Rate of recovery (upon infection)		
initI	Init number of exposed individuals		
initE	Init number of infectious individuals		
initR	Init number of recovered individuals		
initF	Init number of infection-related fatalities		
phi	flux matrix		
checkpoints		Checkpoints	

Infrastructure

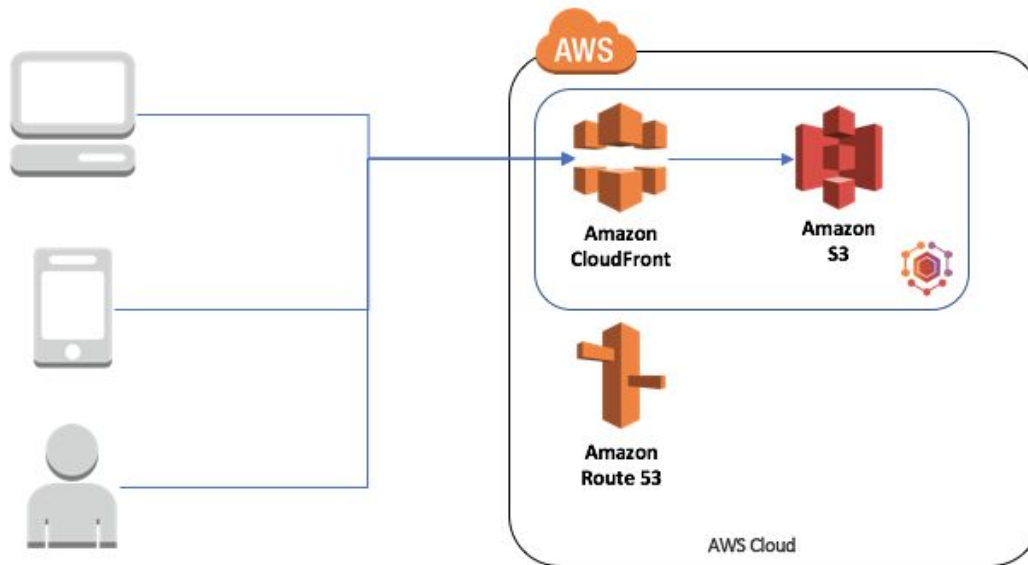
The main objective of this section is to describe the architecture and resources required to deploy the COVID-19 Model web application.

Infrastructure Architecture

Backend



Frontend



AWS Resources

User Account

- A User Account with access to the following resources.

Frontend

- 2 Buckets of AWS S3, one for Dev and one for Production
- Amazon CloudFront that points to the S3 buckets. (Optional, but this will improve the speed)

Backend

- One public and one private subnet in the same region.
- AWS Elastic Container Service with a Fargate cluster.
- An Application Load Balancer in the public subnet.