Using Compartmental Models to Estimate Health System Requirements for COVID-19 Pandemic Response: A Philippine Study

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Introduction

The COVID-19 pandemic posed major challenges to health systems across the globe over the past three years.

For a lower-middle income class country such as the Philippines with limited resources, its health system is more susceptible to being overwhelmed whenever there is a surge of COVID-19 infections and hospitalizations.

The monitoring and management of health capacity is a key component in the Philippine government's pandemic response.

To contribute to this initiative, the FASSSTER team developed compartmental models and provided corresponding outputs that would give a picture of the potential burden that the Philippine health system may face over the course of this pandemic.

FASSSTER: **F**easibility **A**nalysis on **S**yndromic **S**urveillance using **S**patio-**T**emporal **E**pidemiological modele**R**

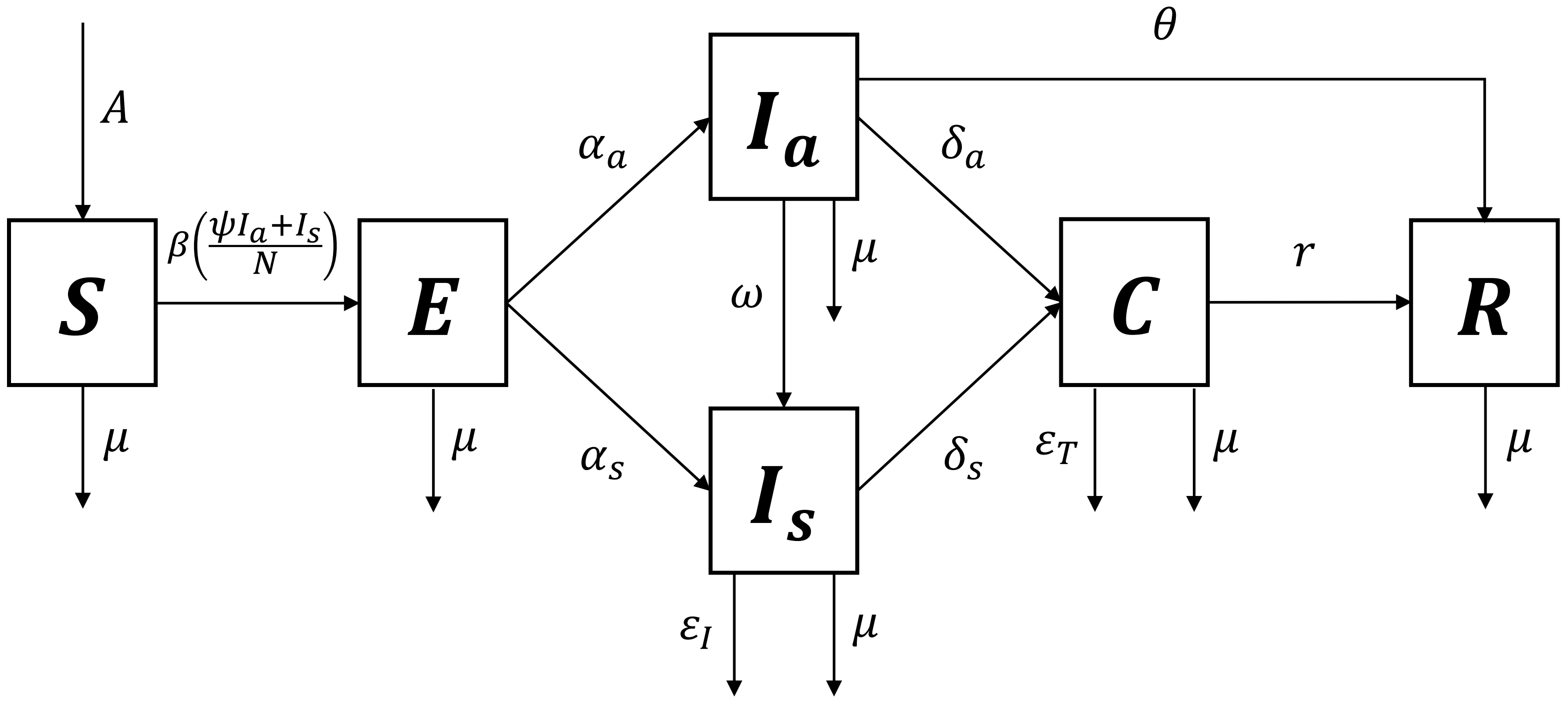
FASSSTER
Feasibility Analysis of Syndromic Surveillance Using a Spatio-Temporal Epidemiological Modeler For Early Detection of Diseases

First Phase

March 2020 – June 2021

Wild-Type Strain + Initial VOC's

FASSSTER COVID-19 Model I



S	**Susceptible**
E	**Exposed**
Ia	**Infectious and Asymptomatic**

Is	**Infectious and Symptomatic**
C	**Confirmed**
R	**Recovered**

Estimating Hospital Requirements

The SEIR model can be used to estimate the healthcare requirements such as the number of beds and the number of healthcare workers needed per day in order to meet the needs of the patients.

Estimates are based on the projections of active cases. The succeeding estimates will be based on the following assumption:

Percentage of Active Cases	COVID-19 Clinical Status
80%	Mild or Asymptomatic
19%	Moderate or Severe
1%	Critical

Estimating Hospital Requirements: Formulas

Let ModSev = Number of Moderate or Severe Cases,

Crit = Number of Critical Cases

It will be assumed that each healthcare worker will be working on an 8-hour shift; therefore, the total number per day is estimated for three 8-hour shifts.

Item	Assumptions	Formula
Regular Beds	All moderate and severe cases will stay in regular beds	$=ModSev$
Doctors for Regular Beds	1 doctor per 10 regular beds	$=\frac{Regular\ Beds}{10} \times 3$
Nurses for Regular Beds	1 nurse per 7 regular beds	$=\frac{Regular\ Beds}{7} \times 3$

Item	Assumptions	Formula
ER Beds	Only moderate and severe cases will go to ER. Each ER patient will stay in ER for 3 hrs.	$= \frac{ModSev}{8}$
ER Doctors	1 doctor per 6 ER beds	$= \frac{ER\ Beds}{6} \times 3$
ER Nurses	1 nurse per 6 ER beds	$= \frac{ER\ Beds}{6} \times 3$
ICU Beds	All critical cases will require ICU	$= Crit$
ICU Doctors	1 doctor per 4 ICU beds	$= \frac{ICU\ Beds}{4} \times 3$
ICU Nurses	1 nurse per 2 ICU beds	$= \frac{ICU\ Beds}{2} \times 3$

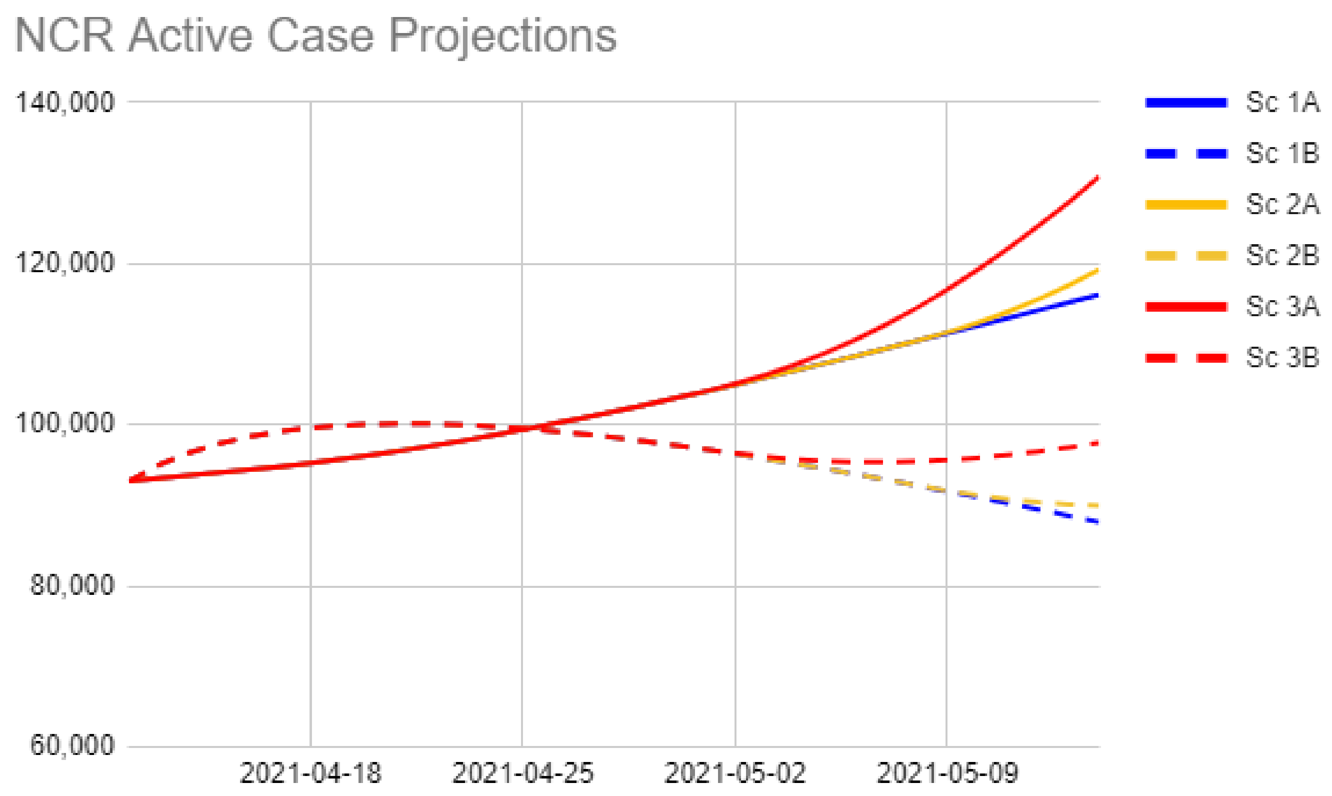
Projection Outputs

Community Quarantines (CQs): These are policies imposed by the government that greatly reduce mobility and physical interactions within a community.

In decreasing order of stringency, these are the CQ classifications:

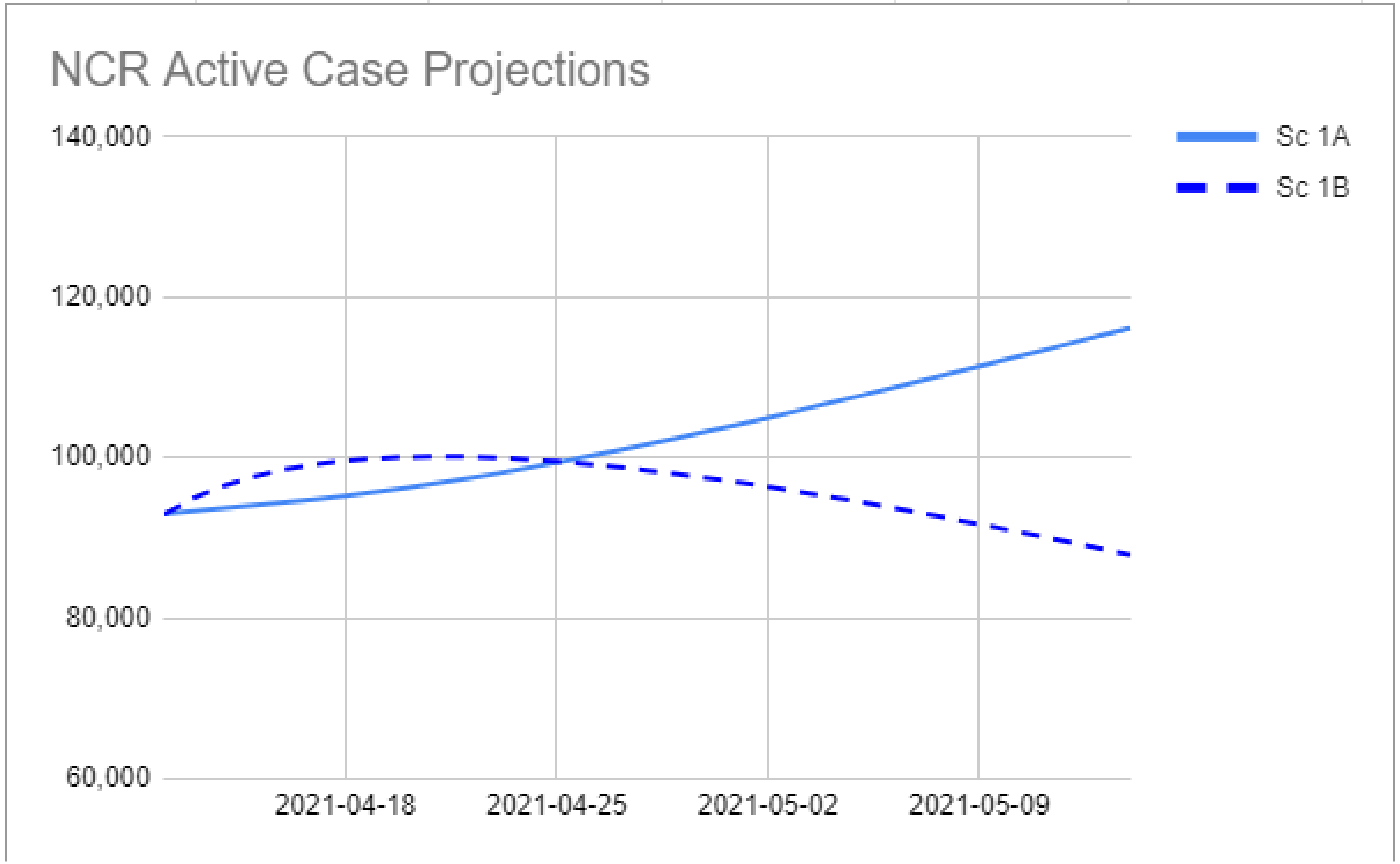
- Enhanced Community Quarantine (ECQ)
- Modified Enhanced Community Quarantine (MECQ)
- General Community Quarantine (GCQ)
- Modified General Community Quarantine (MGCQ)

NCR Active Case Projections for the period April 12 to May 14, 2021



	April 12-30	May 1-7	May 8-14	HSC
Scenario 1A	MECQ	MECQ	MECQ	Current
Scenario 1B	MECQ	MECQ	MECQ	Improved
Scenario 2A	MECQ	MECQ	GCQ	Current
Scenario 2B	MECQ	MECQ	GCQ	Improved
Scenario 3A	MECQ	GCQ	GCQ	Current
Scenario 3B	MECQ	GCQ	GCQ	Improved

NCR Active Case Projections for the period April 12 to May 14, 2021



	April 12-30	May 1-7	May 8-14	HSC
Scenario 1A	MECQ	MECQ	MECQ	Current
Scenario 1B	MECQ	MECQ	MECQ	Improved
Scenario 2A	MECQ	MECQ	GCQ	Current
Scenario 2B	MECQ	MECQ	GCQ	Improved
Scenario 3A	MECQ	GCQ	GCQ	Current
Scenario 3B	MECQ	GCQ	GCQ	Improved

The table below provides estimates of the required number of hospital beds and attending doctors if the NCR were to be placed under MECQ on April 12 to May 14, 2021.

The maximum and average numbers were calculated prior to April 12 based on the projected number of cases under MECQ scenario and the given formulas.

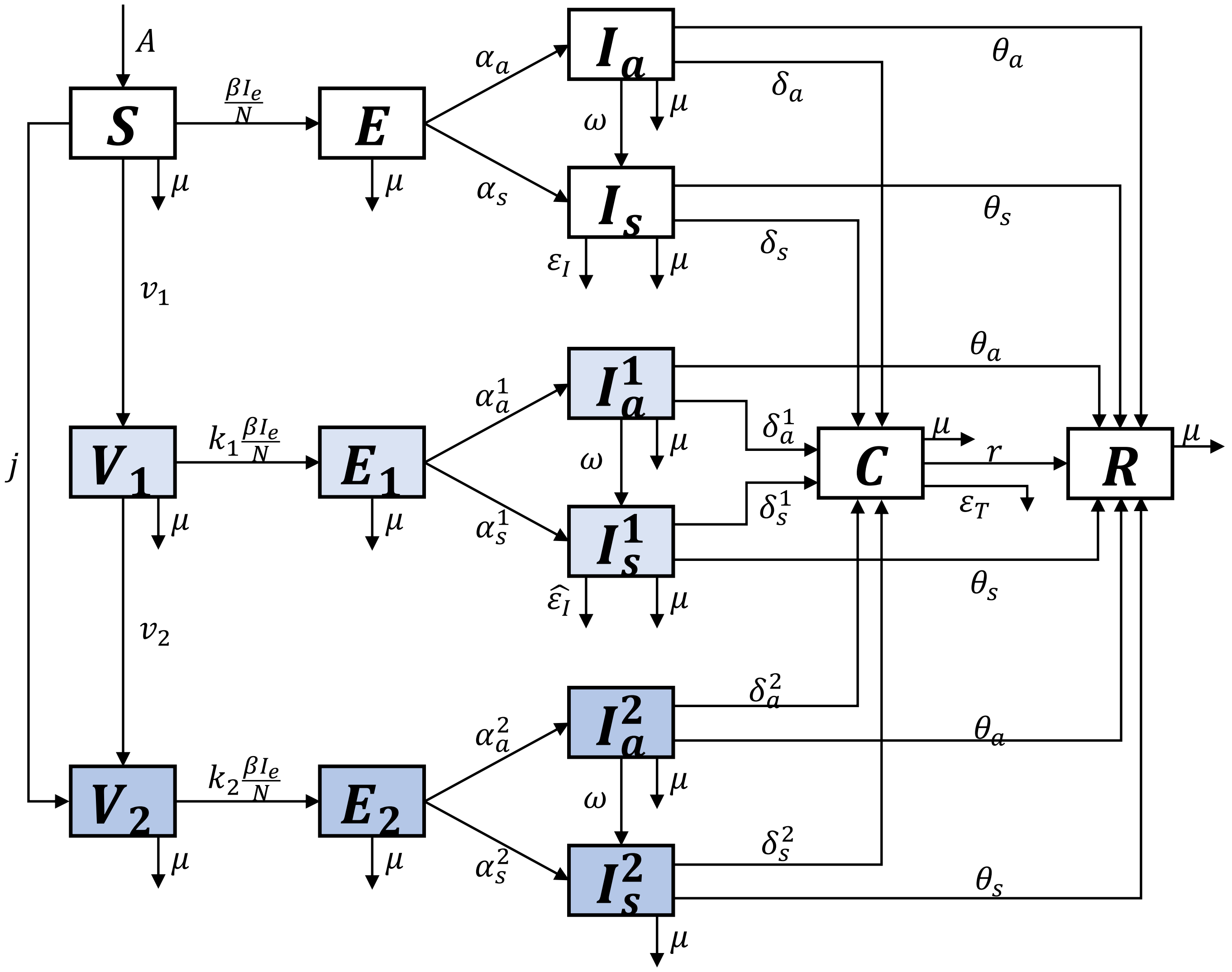
	Maximum	Average
ICU Beds	1,161	1,027
Regular Beds	22,063	19,513
ER Beds	2,758	2,439
ICU Doctors	871	770
Regular Doctors	6,619	5,854
ER Doctors	1,379	1,220

Second Phase

July 2021 – December 2021

Delta Variant + Vaccination

FASSSTER COVID-19 Model II



S, V_1, V_2	**Susceptible (unvaccinated and vaccinated)**
E, E_1, E_2	**Exposed**
I_a, I_a^1, I_a^2	**Infectious and Asymptomatic**
I_s, I_s^1, I_s^2	**Infectious and Symptomatic**
C	**Confirmed**
R	**Recovered**

Estimating Severe and Critical Case Counts

During this phase, the focus was to produce severe and critical case estimates. These estimates will be based on the active case projections.

Because of the model structure and the lack of available data, we needed to a have a breakdown of the active case numbers according vaccination status (i.e., unvaccinated, partially vaccinated and fully vaccinated), and then determine the corresponding severe and critical percentage applicable to each subgroup.

Vaccine Effectiveness Values

V_i (vs. infection)

$$V_e = V_i + V_s(1 - V_i)$$

V_s (vs. symptomatic disease given infection)

V_e (vs. symptomatic disease)

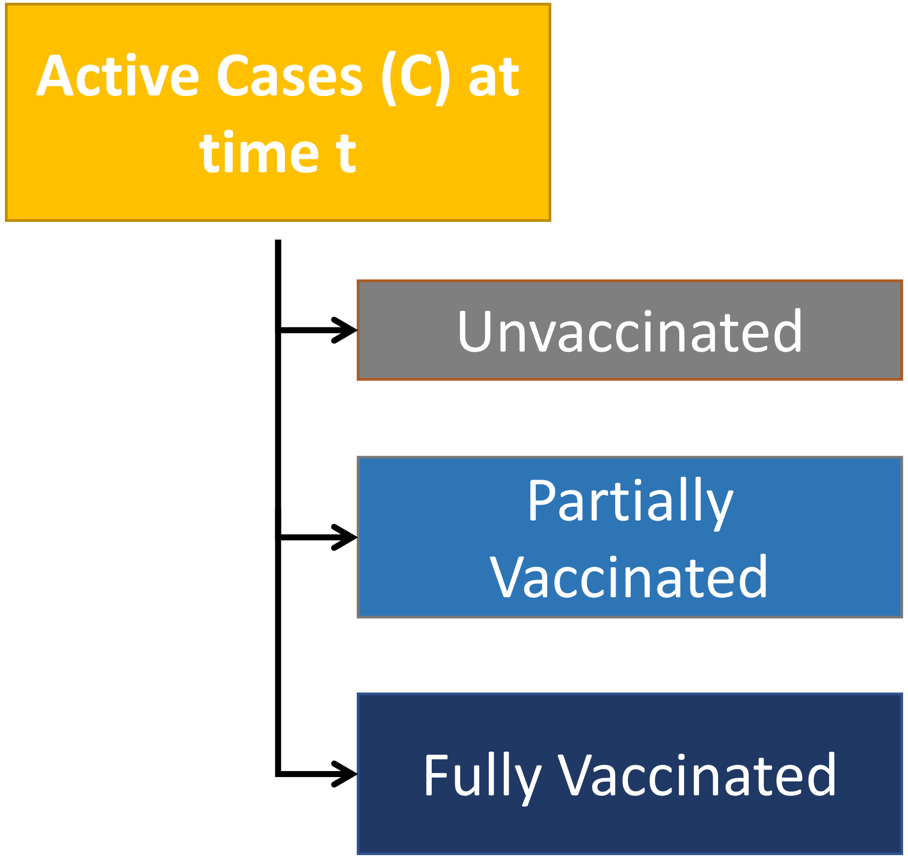
V_e (vs. symptomatic disease)

$$V_h = V_e + V_{ch}(1 - V_e)$$

V_{ch} (vs. hospitalization given symp. disease)

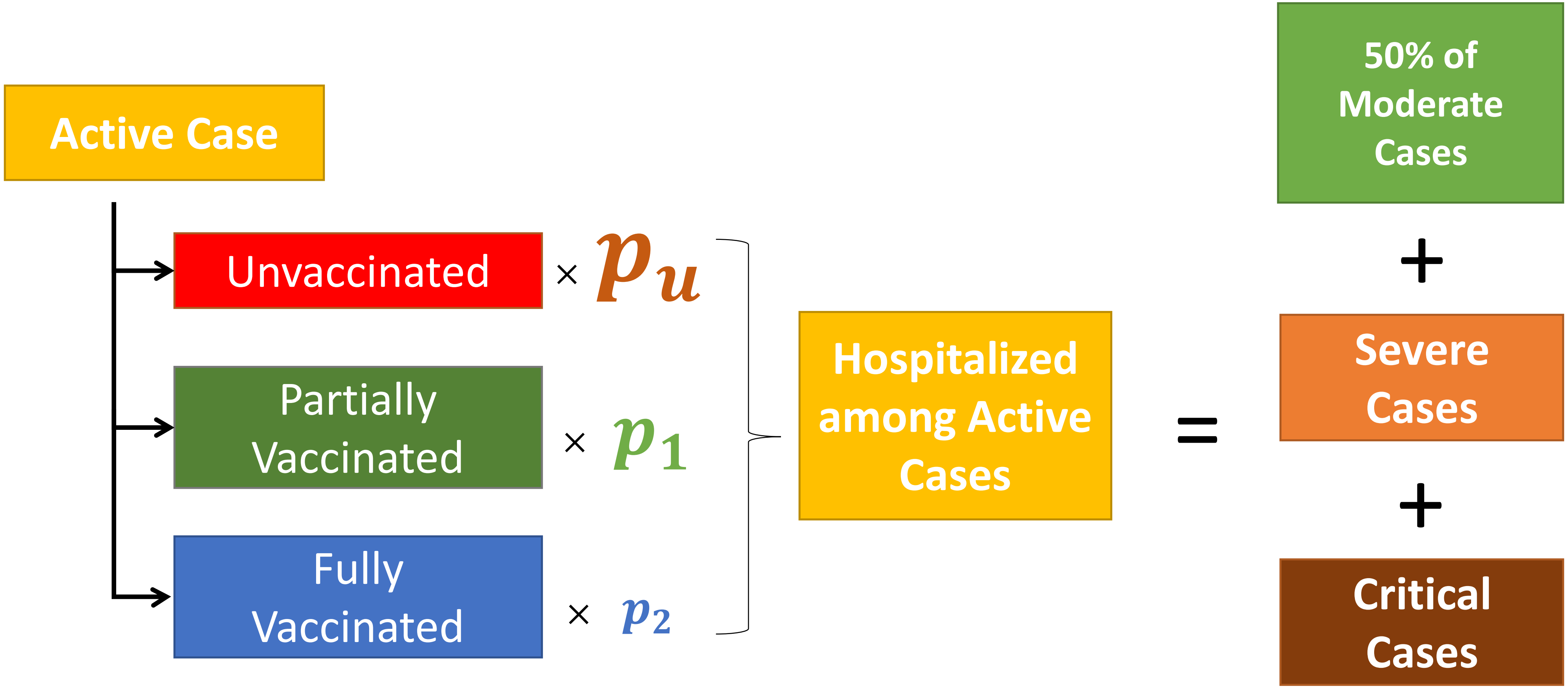
V_h (vs. hospitalization)

Breakdown of Active Case Numbers According to Vaccination Status



$$\frac{\text{number of unvaccinated (partially vaccinated, fully vaccinated) infectious individuals who were detected within the past two weeks from day } t}{\text{number of infected individuals who were detected within the past two weeks from day } t}$$

Percentage of severe and critical for each subgroup

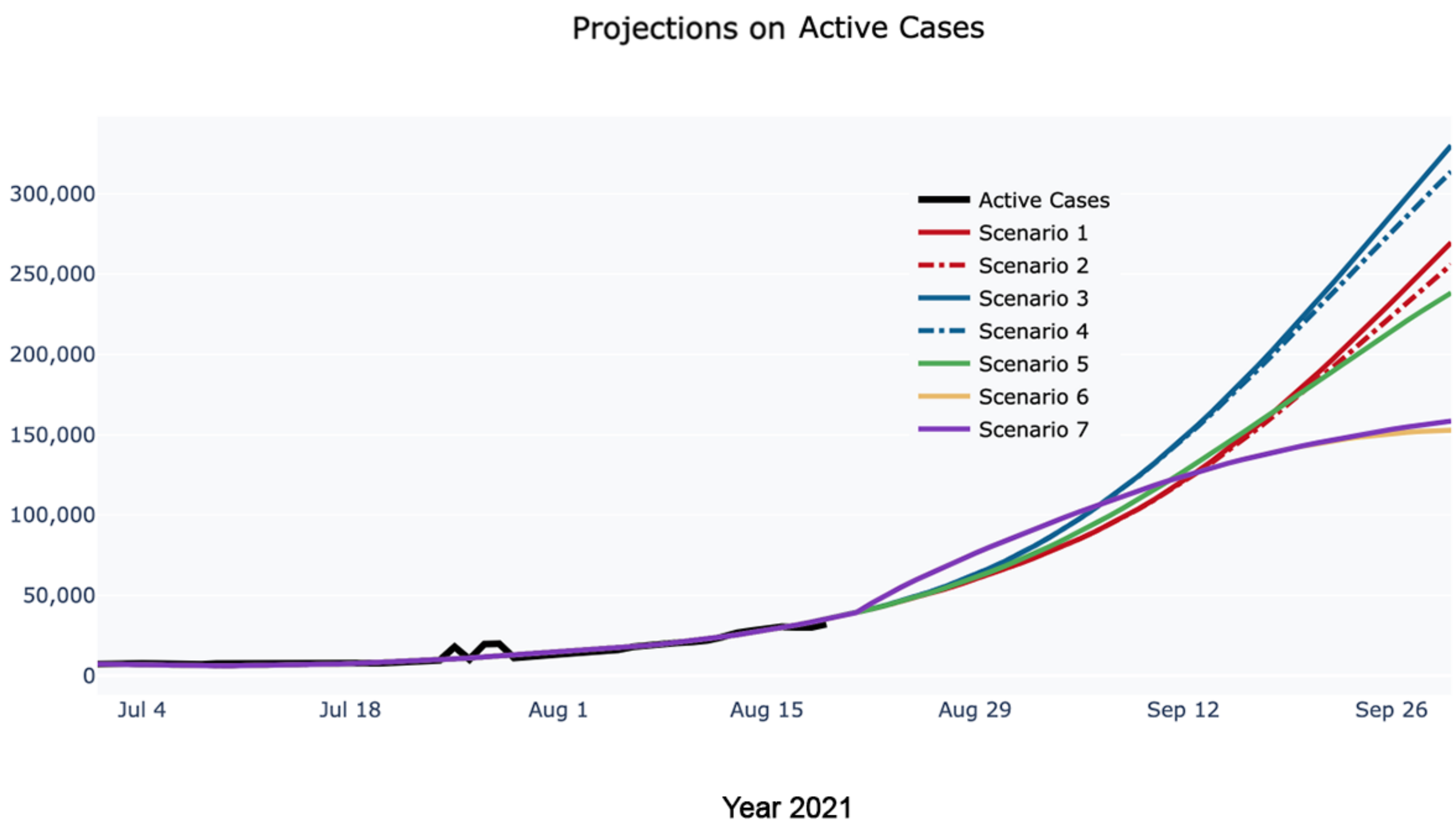


p_u, p_1, p_2 represent the proportion of hospitalized cases among the **unvaccinated**, **partially vaccinated** and **fully vaccinated**, respectively

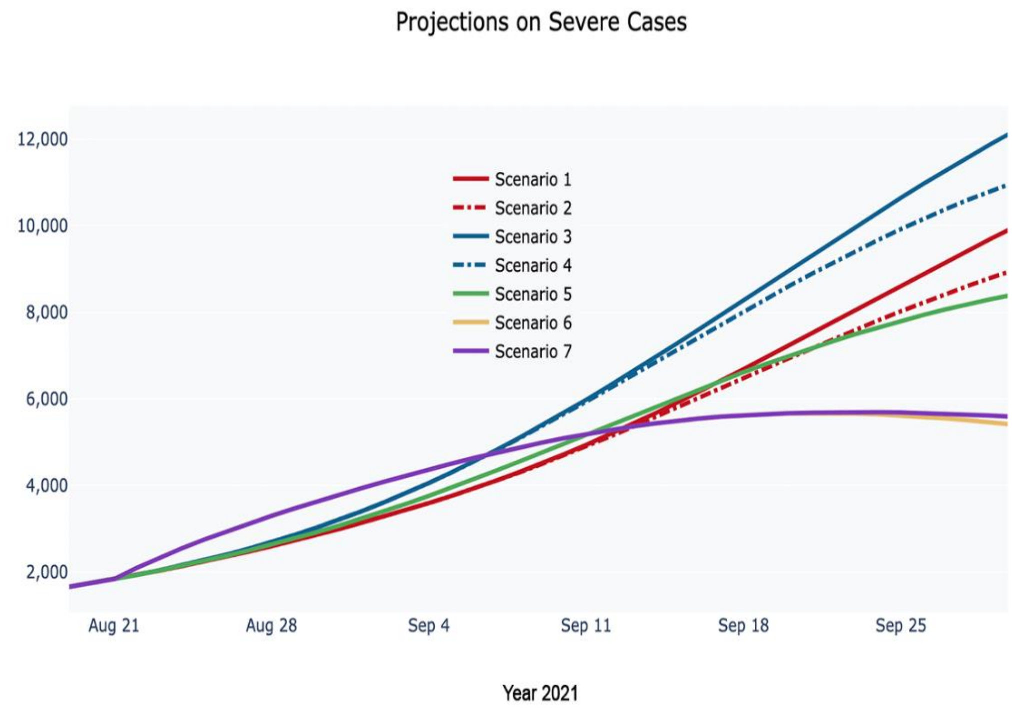
Projection Outputs

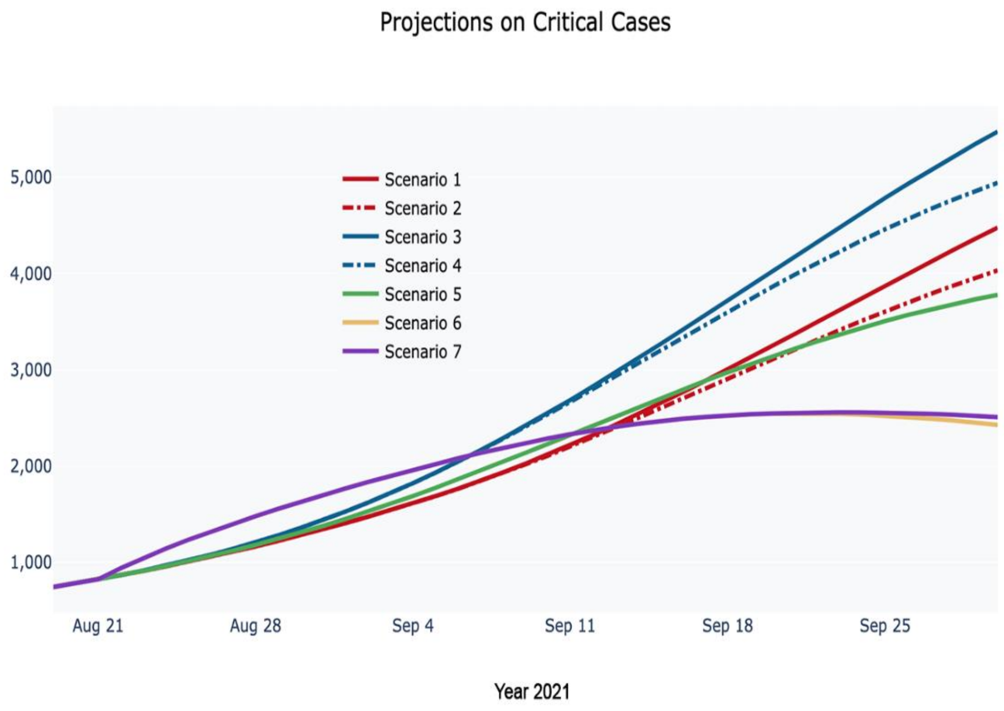
Scenario	CQ Policy (from 8-21-21)	Vax Rate	HSC	MPHS
Scenario 1	ECQ (2 weeks) + MECQ (4 weeks)	Current	Current	Current
Scenario 2	ECQ (2 weeks) + MECQ (4 weeks)	Improved	Current	Current
Scenario 3	MECQ (6 weeks)	Current	Current	Current
Scenario 4	MECQ (6 weeks)	Improved	Current	Current
Scenario 5	MECQ (6 weeks)	Improved	Current	Improved
Scenario 6	MECQ (6 weeks)	Improved	Improved	Improved
Scenario 7	MECQ (4 weeks) + GCQ (2 weeks)	Improved	Improved	Improved

NCR Active Case Projections for the period Aug. 21 to Sept. 30, 2021



Severe and Critical Case Projections for the period Aug. 21 to Sept. 30, 2021



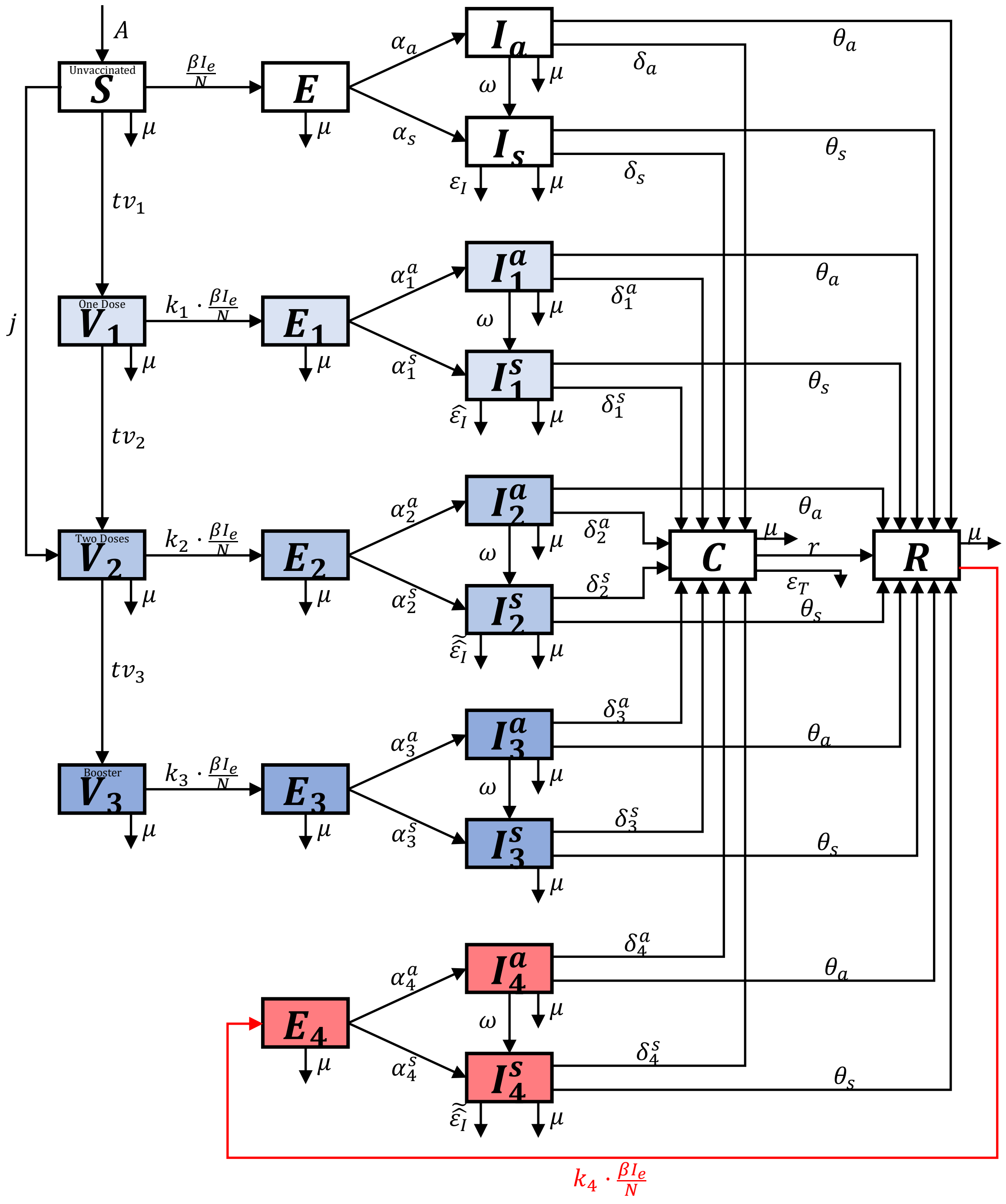


Third Phase

January 2022 – present

Omicron Variant + Boosters + Reinfection

FASSSTER COVID-19 Model III

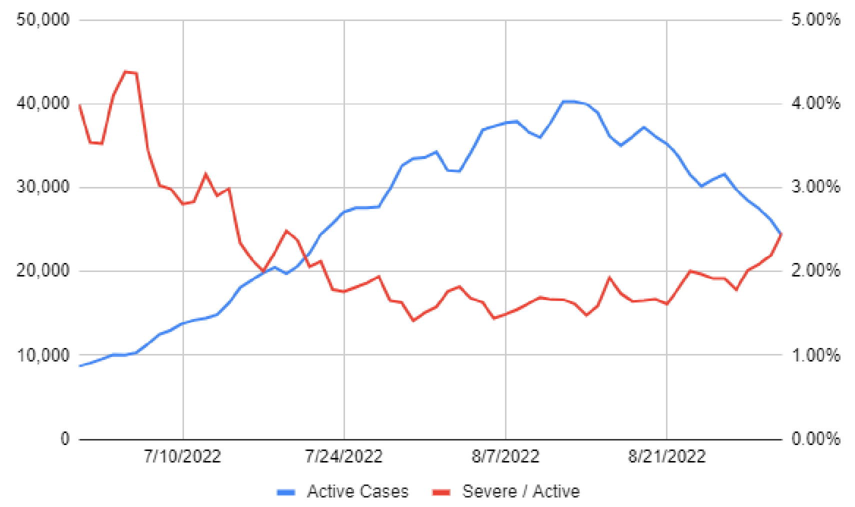


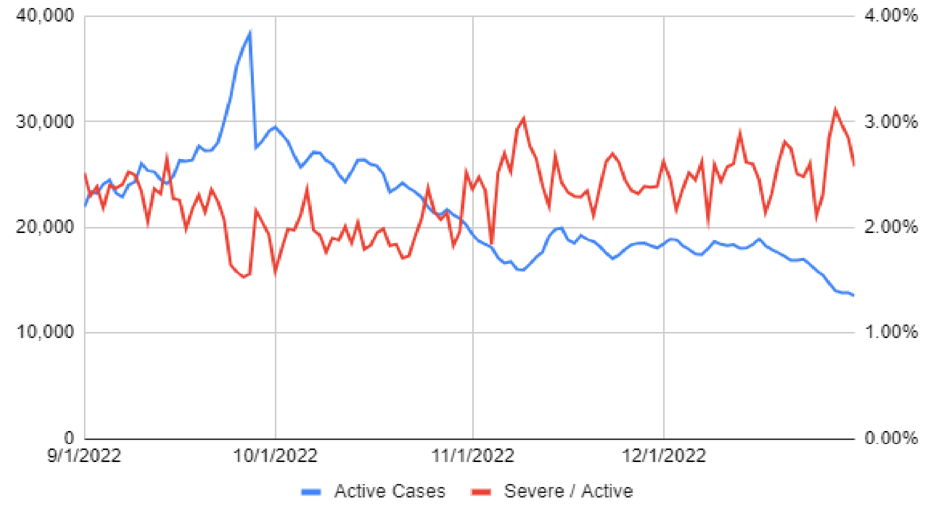
S, V_1, V_2, V_3	Susceptible (unvaccinated and vaccinated)
E, E_1, E_2, E_3, E_4	Exposed
$I_a, I_1^a, I_2^a, I_3^a, I_4^a$	Infectious and Asymptomatic
$I_a, I_1^s, I_2^s, I_3^s, I_4^s$	Infectious and Symptomatic
C	Confirmed
R	Recovered (and can be reinfected)

A similar method was initially employed for estimating severe and critical case counts, but we used hazard ratios against omicron hospitalization (from UKHSA) instead of vaccine effectiveness against hospitalization.

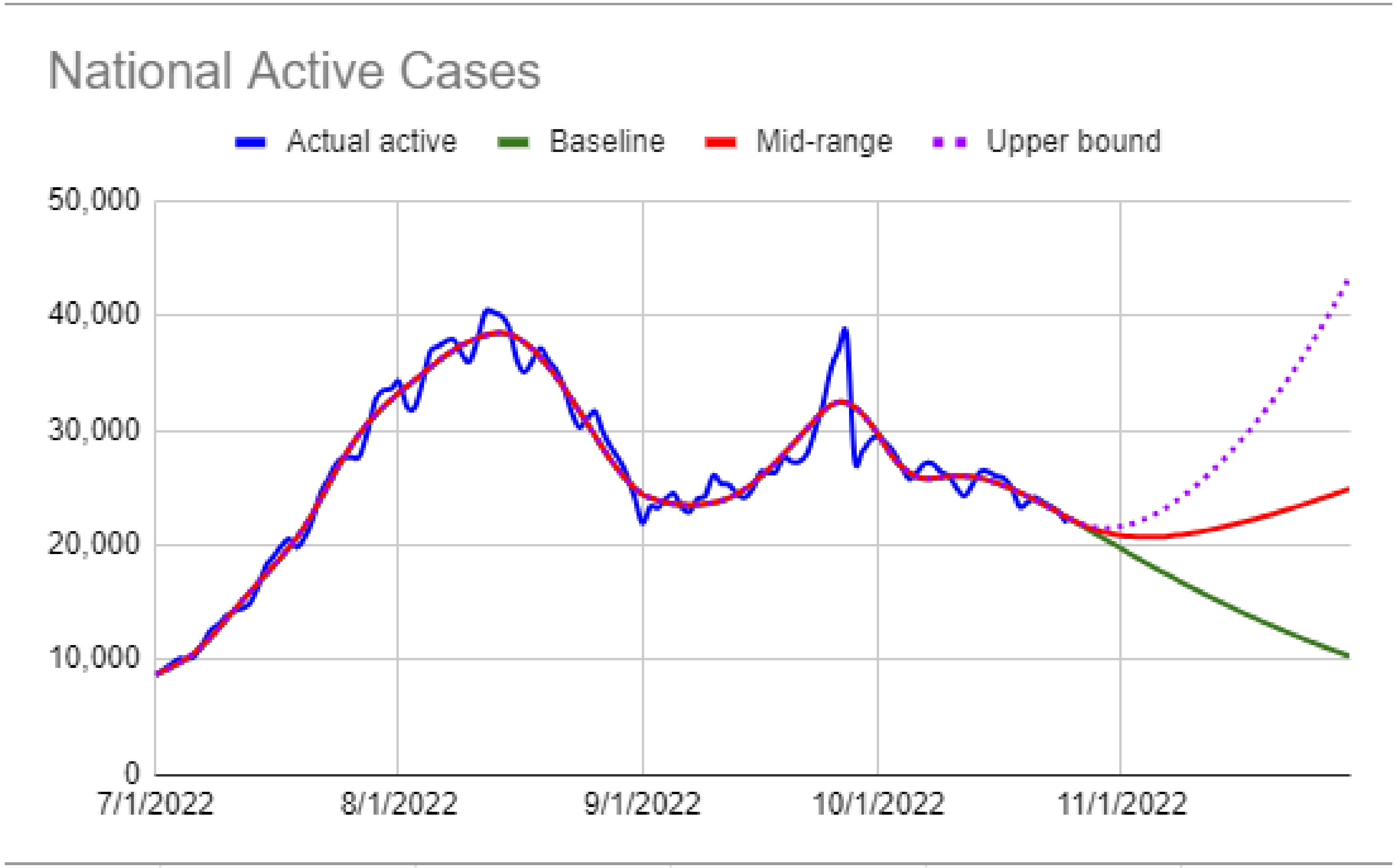
However, the corresponding outputs did not always match the observed case counts, hence we had to seek other means of estimating these outcomes.

Relationship between Active cases and Severe percentage





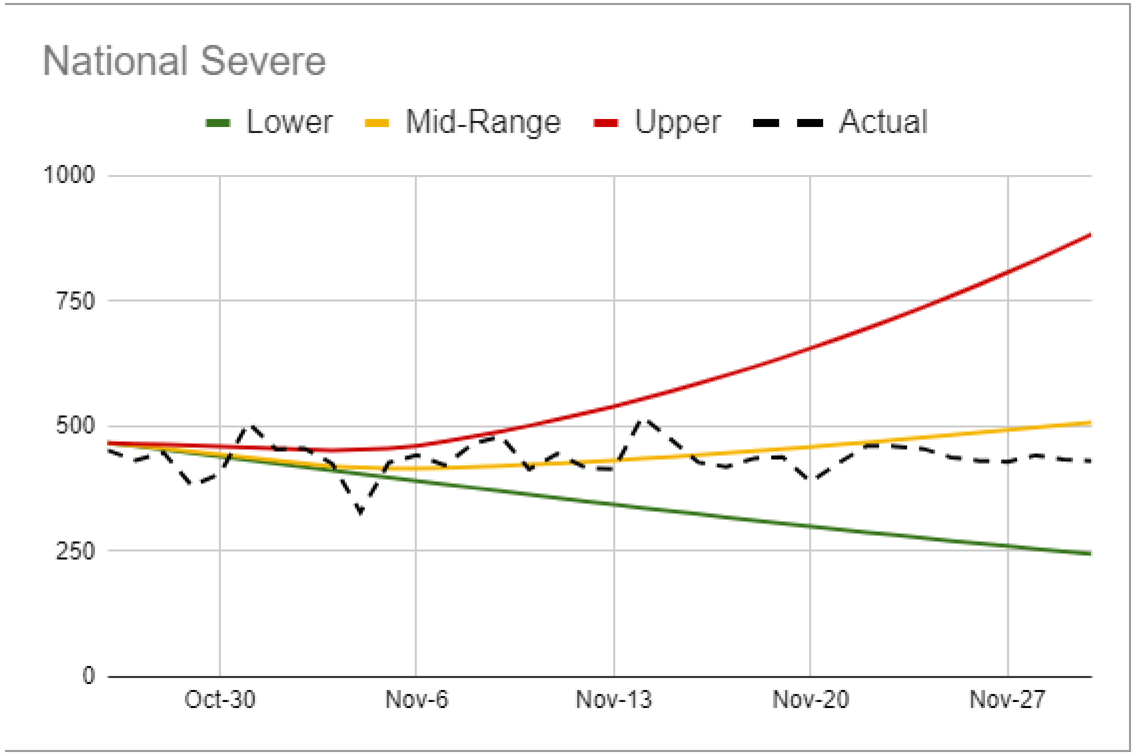
Projection Outputs

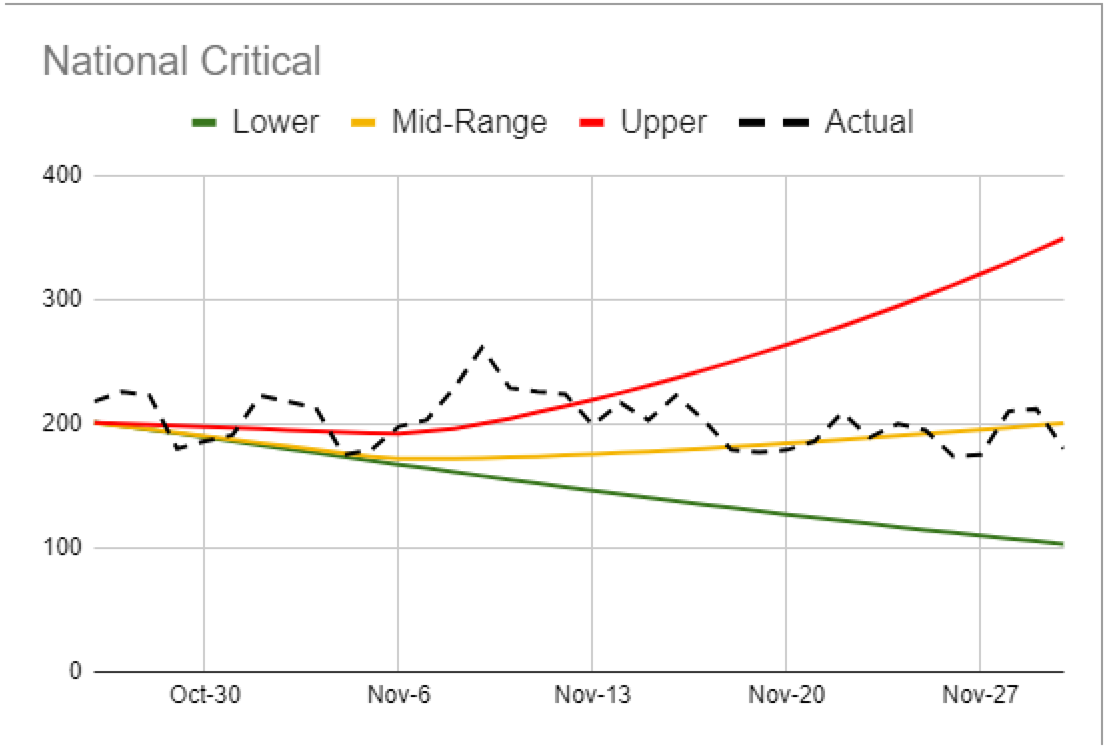


The scenarios are based on varying levels of MPHS compliance

Scenario	Trendline for Sev %
Lower	$y = -0.00599 + 0.0032\ln(x)$
Middle	$y = =0.0138-0.00115\ln(x)$
Upper	$y = =0.0138-0.00115\ln(x)$

Scenario	Trendline for Crit %
Lower	$y = -0.0234 + 0.00943\ln(x)$
Middle	$y = 0.0106 + 0.00196\ln(x)$
Upper	$y = 0.0106 + 0.00196\ln(x)$





Looking Ahead

Machine Learning Model

Background: Neural Network

Neural networks represent a class of machine learning algorithms that mimics how neurons in the brain work.

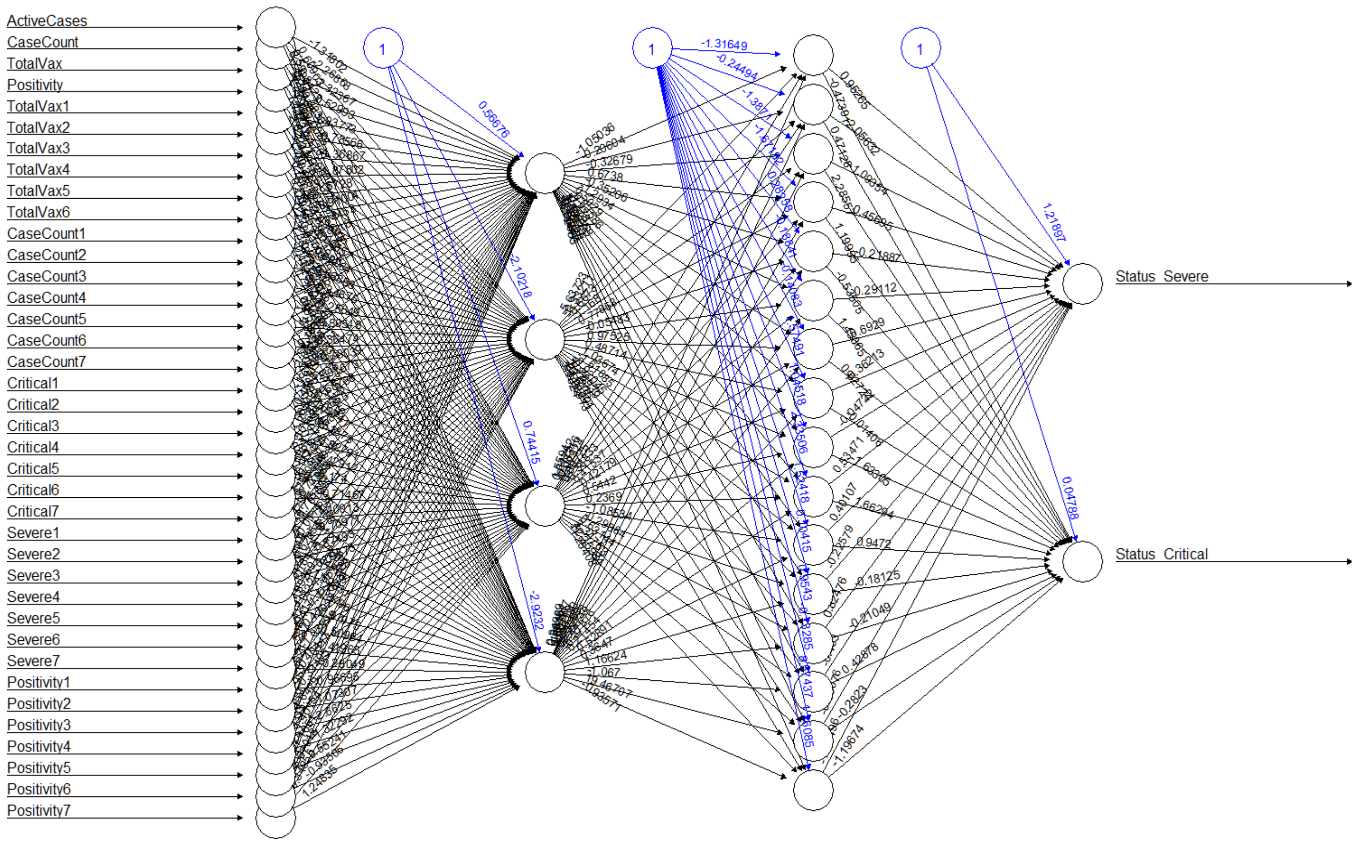
The “neurons” (nodes) in layer $l-1$ will each send “signal” (value) to the “neurons” in layer l.

Each of the “neurons” in layer l will then “process” (transform) these “signals” , before passing them on to the “neurons” in layer $l+1$.

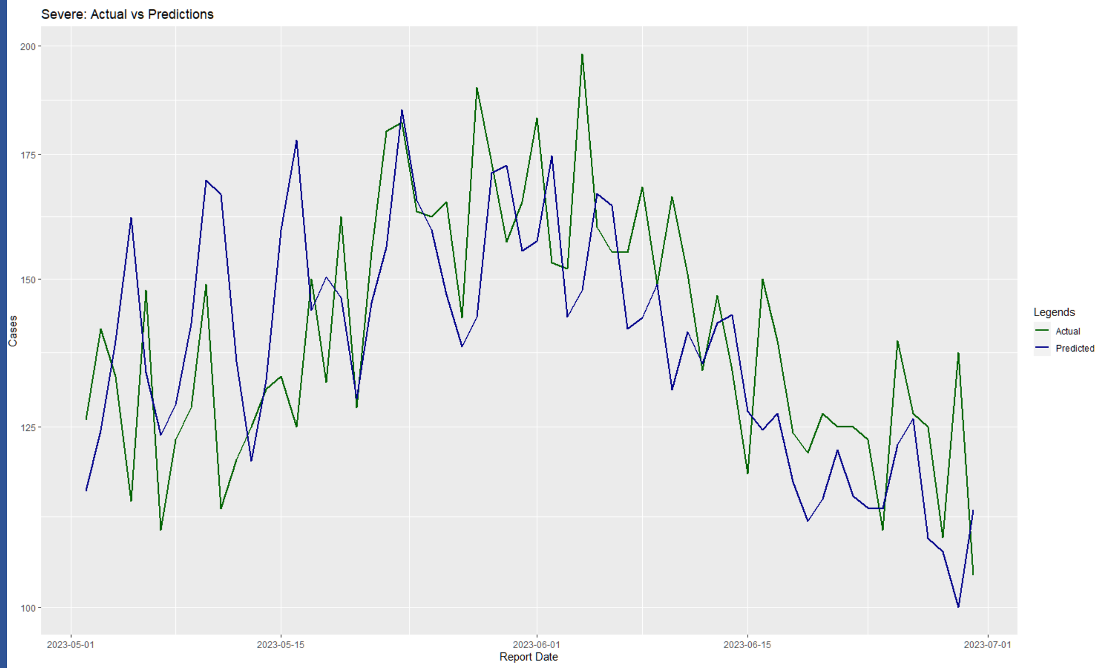
The transformation is through a nonlinear parametric regression.

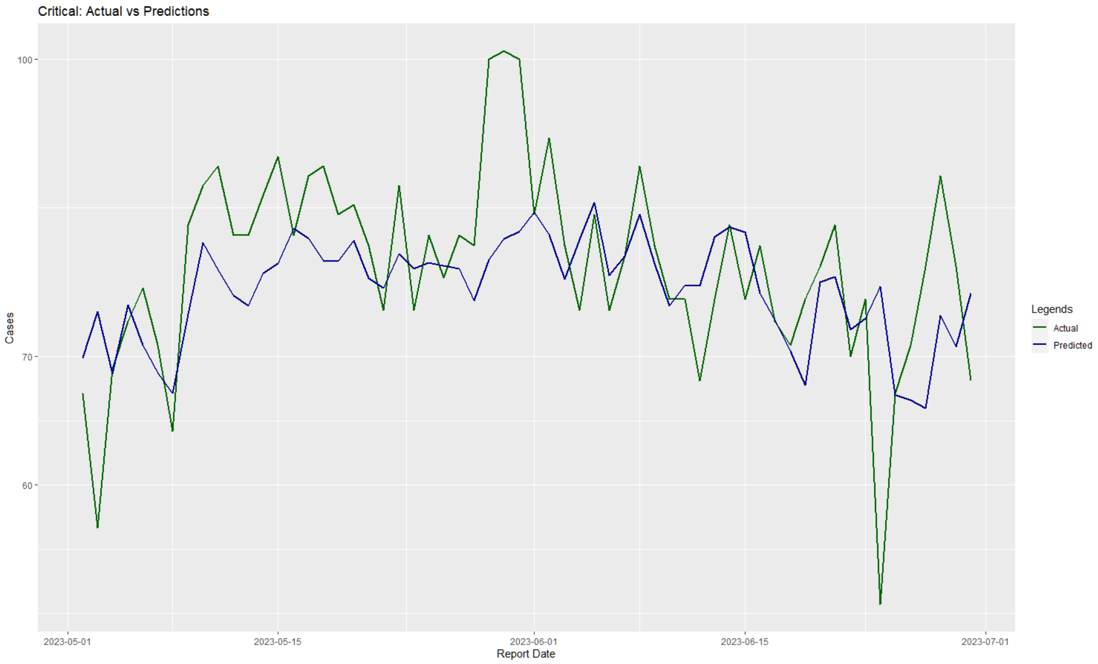
Network Architecture

- Input: 38 variables
  - active cases (t)
  - daily case counts (t, t-1, …, t-7)
  - daily vaccinations (t, t-1, …, t-6)
  - positivity rate (t, t-1, …, t-7)
  - severe case (t-1, …, t-7)
  - critical cases (t-1, …, t-7)
- Output: 2 variables
  - severe cases (t)
  - critical cases (t)
- Two hidden layers
  - 4 nodes for layer $l = 1$
  - 24/14 nodes for layer $l = 2$
- Time frame
  - Train data: May 1, 2022 to April 30, 2023
  - Test data: May 1, 2023 to June 30, 2023



Preliminary Results: Actual vs Predictions





Severe (4,24)

Accuracy: 0.89

Critical (4,14)

Accuracy: 0.777

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