CORONAVIRUS

COVID-19

INTRODUCTION

We aim to extend our understanding of the SEIR model by introducing additional compartments. Then, we will fit the data using the model. Finally, introduce a model named SVIR.

QUESTIONS

1 Will adding quarantining and confinement compartments will capture the behavior of Coronavirus ?

2 How reliable is it to use modified SEIR model with addition of quarantining and confinement to forecast cases in the UAE ?

3 Will the 2^{nd} waves of coronavirus influence our fitted curves ?

QUESTIONS

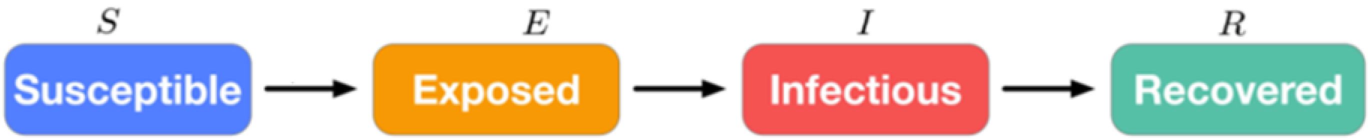
4 What fraction of the population must be vaccinated to eliminate the virus?

5 What happens if the target coverage for eradication is not met?

6 Does it matter if vaccine induced immunity wanes with time?

Methods:

- **SEIR model:**



Basic framework of SEIR model.

susceptible population S(t): healthy individuals who have not been exposed to the disease.	*exposed population E(t):* infected individuals whose symptoms still did not appear, and they cannot infect others.
infected population I(t): individuals who exhibits signs and symptoms of the illness.	*recovered population R(t):* individuals who can no longer infect others (recovered or died)

Methods:

- **SEIR model:**

$$\frac{dS}{dt} = -\beta S(I + qE)/N$$
$$\frac{dE}{dt} = \beta S(I + qE)/N - E/\delta$$
$$\frac{dI}{dt} = E/\delta - I/\gamma$$
$$\frac{dR}{dt} = I/\gamma$$

- β: is the contact rate which is the average number of contacts per person per time and it may be a function of time.
- q: is a scaling factor.
- 1/δ: infection rate (rate of transfer from the exposed to the infectious stage).
- $1/\gamma$: *recovery rate.*
- γ: is the average time it takes a person to die or recover once in the infectious stage.

Our previous model studied :

1. **Age compartment**

Children (0-18 years old)
Young adults (18-30 years old)
Adults (30-70 years old)
Elderly (Above 70 years old)

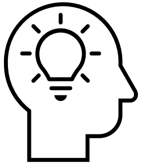
2. **Mobility restriction**

Based on different location such as schools, parks, bars and so on.

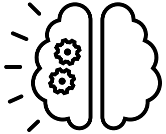
3. **Social distancing effect**

By decreasing the rate of interactions between people.

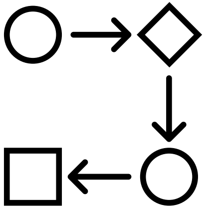
What we wanted to investigate in our new model:



1. To study the effect of adding the quarantine and confinement compartments



2. To fit our model based on the UAE data



3. To study the effect of Vaccination

Our assumptions:

- With the same birth and death rates, the population stays constant.
- Individuals that have been infected are quarantined and are not allowed to interact with someone who is susceptible. This ensures that the chances of infecting a protected susceptible are extremely low.
- When a susceptible person comes into contact with an infected person who is undetected, they become contagious

Our modified model:

$$\frac{dS(t)}{dt} = -\alpha S(t) - \beta \frac{S(t)I(t)}{N_{pop}}$$

$$\frac{dE(t)}{dt} = -\gamma E(t) + \beta \frac{S(t)I(t)}{N_{pop}}$$

$$\frac{dI(t)}{dt} = \gamma E(t) - \delta I(t)$$

$$\frac{dQ(t)}{dt} = \delta I(t) - \lambda(t)Q(t) - \kappa(t)Q(t)$$

$$\frac{dR(t)}{dt} = \lambda(t)Q(t)$$

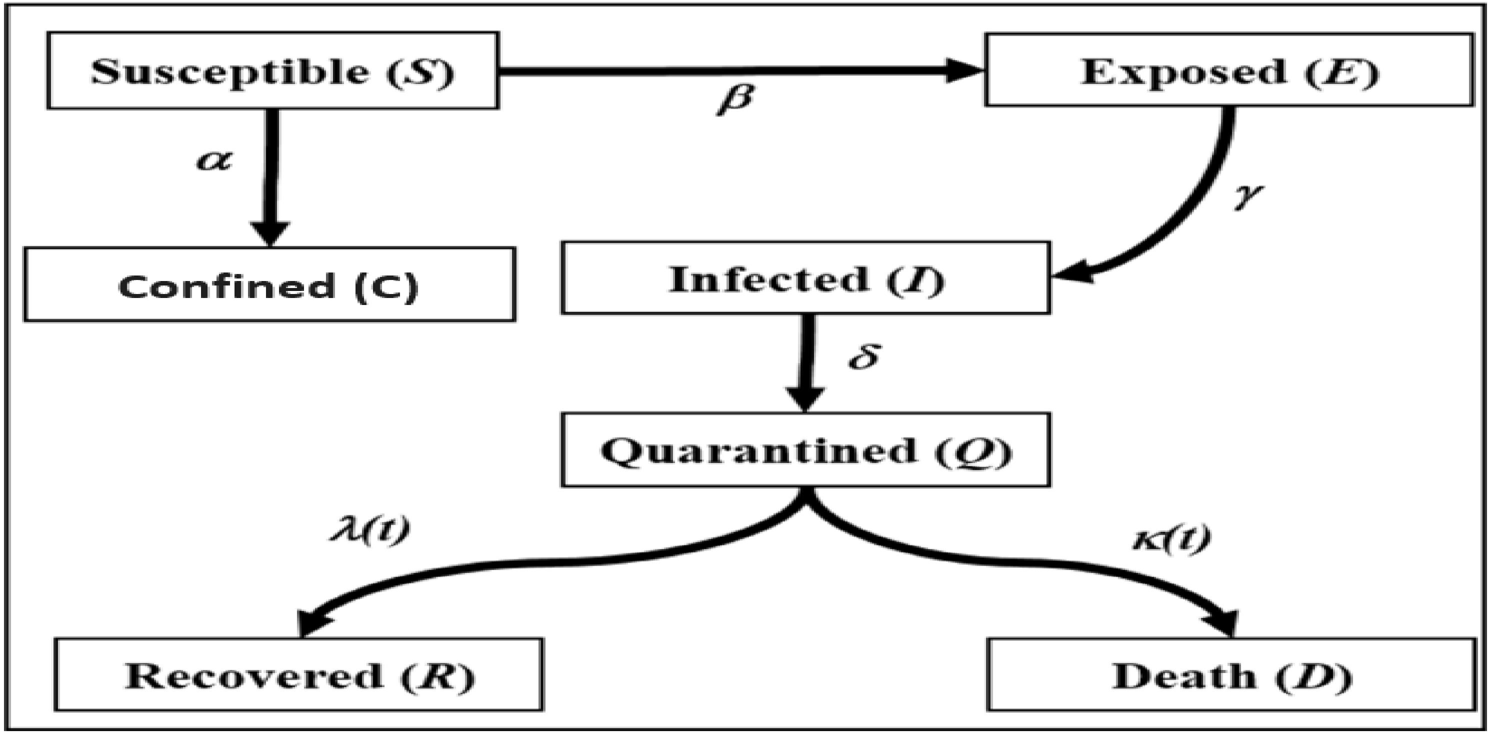
$$\frac{dD(t)}{dt} = \kappa(t)Q(t)$$

$$\frac{dC(t)}{dt} = \alpha S(t)$$

Table 1: Main Model Parameter

Parameter	Description
α	Protection parameter
β	Transmission parameter
γ	Recovery parameter
δ	Rate at which people enter in quarantine
$\lambda(t)$	Time-dependant recovery rate
$\kappa(t)$	Time-dependant mortality rate

Epidemic model



Recovery and mortality rates

Recovery and Mortality rates are both time dependent , given as follows

Recovery rate:	Mortality rate:
$\lambda(t) = \lambda_0\left(1 - e^{(-\lambda_1 t)}\right)$	$k(t) = k_0 e^{(-k_1 t)}$

Where λ_0 , $\lambda_1, \kappa_0, \kappa_1$ will be empirically determined based on the data given

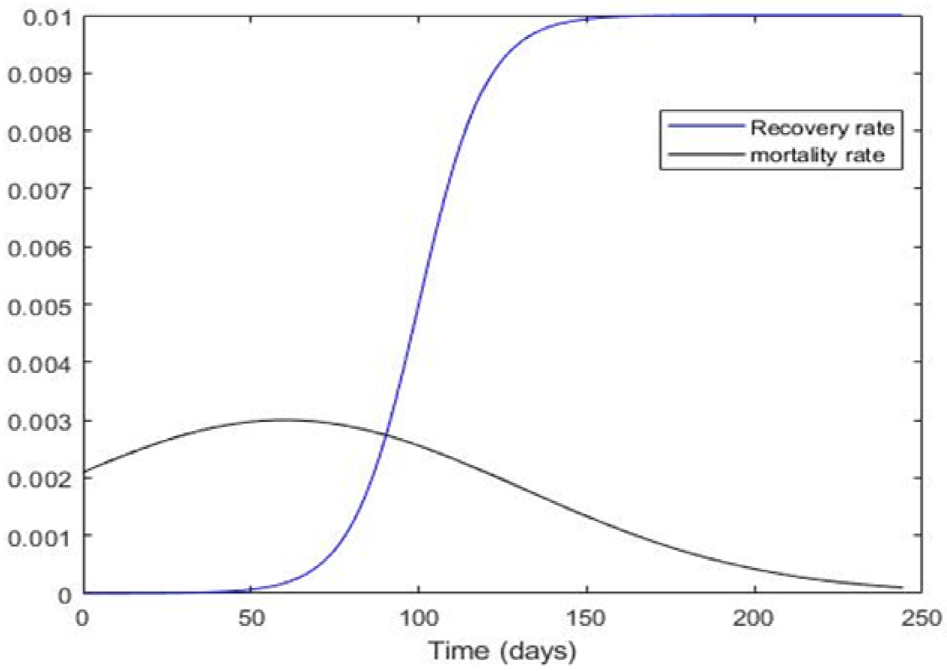


Figure : Demonstrative graph for time dependent rates

Numerical Solution

We re-write the system of ODEs in a matrix form for the sake of clarity:

$$\boxed{dY/dt = A * Y + F}$$

Where

$$A = \begin{bmatrix} -\alpha & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -\gamma & 0 & 0 & 0 & 0 & 0 \\ 0 & \gamma & -\delta & 0 & 0 & 0 & 0 \\ 0 & 0 & \delta & -\kappa(t)-\lambda(t) & 0 & 0 & 0 \\ 0 & 0 & 0 & \lambda(t) & 0 & 0 & 0 \\ 0 & 0 & 0 & \kappa(t) & 0 & 0 & 0 \\ \alpha & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad Y = [S, E, I, Q, R, D, C]^T \quad F = S(t) \cdot I(t) \cdot \begin{bmatrix} -\frac{\beta}{N_{\text{pop}}} \\ \frac{\beta}{N_{\text{pop}}} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

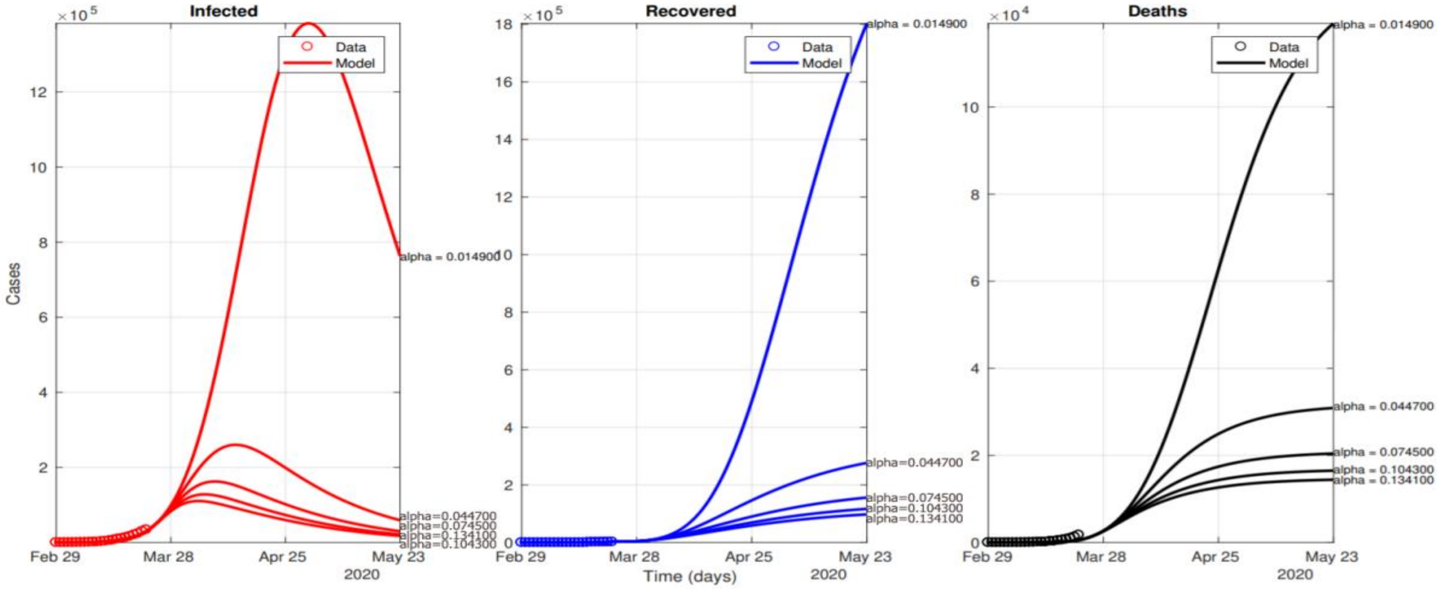
Numerical Solution

We used codes in MATLAB and used 4th order Runge-Kutta method to solve the differential equation, We also tried to estimate the parameters based on least square to plot the overview look of the data

MATLAB Codes available at

Github.com/2thooo/Adjusted_SEIRQCD

The effect of different intervention actions strategies



The model after shifting different values for protection parameter α (Controlled scenario) for Spain.. Obtained from [15]

UAE

Data obtained from Johns Hopkins University's Covid dataset.

https://github.com/CSSEGISandData/COVID-19

Parameter Estimation

Approximated between 1st of April 2020 to 1st of March 2021

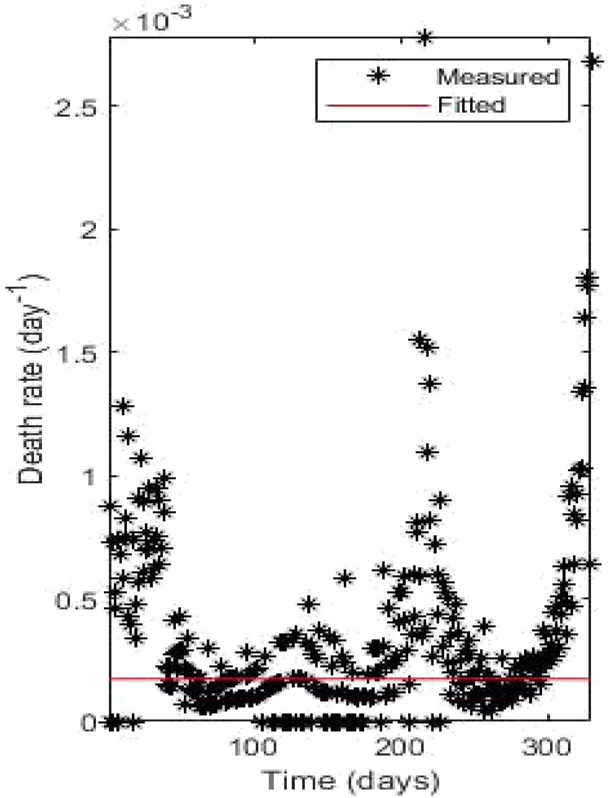
Parameter	UAE (Fitted value)
β	1.2411
α	0.0763
γ	0.32
δ	0.62

Fitted value for time-dependent rates

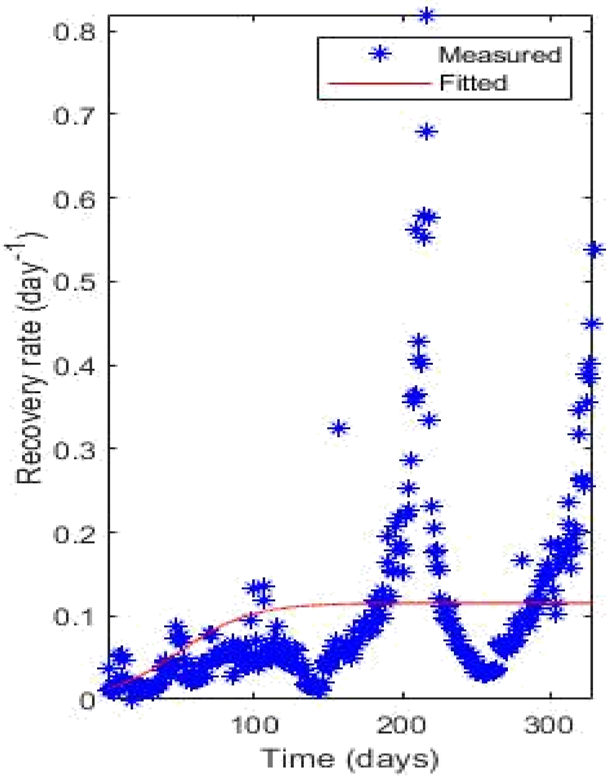
Estimated

$\kappa_0 = 4.6x10^{-4}$
$\kappa_1 = 0.1832$

Mortality Rate



Recovery Rate

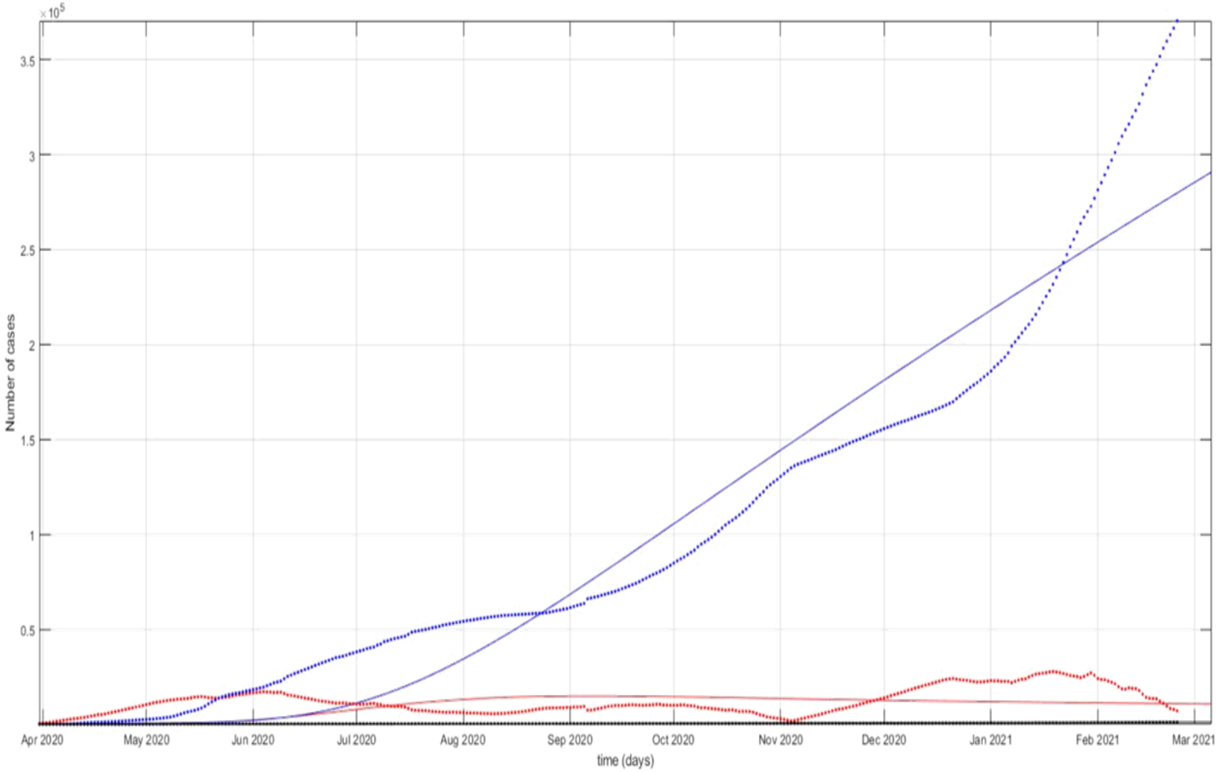


Estimated

$\lambda_0 = 0.1353$
$\lambda_1 = 0.0094$

System Dynamics fitted based on UAE data

(From 1st of April 2020 till 5th of March 2021)

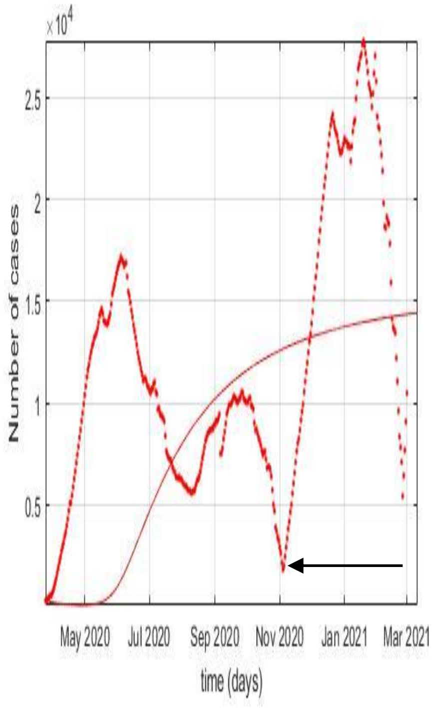


Active (Red)
Recovered (Blue)
Fatalities (Black)

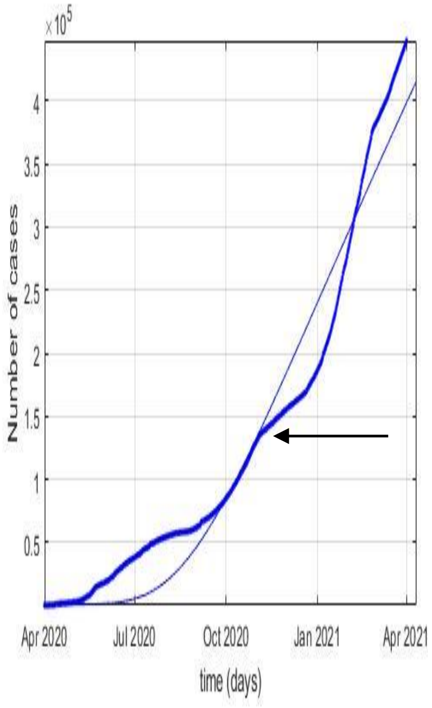
Real Data (**Thick** / Dotted)
SEIRQCD model (Thin line)

System Dynamics (From 1st of April 2020 till 5th of March 2021)

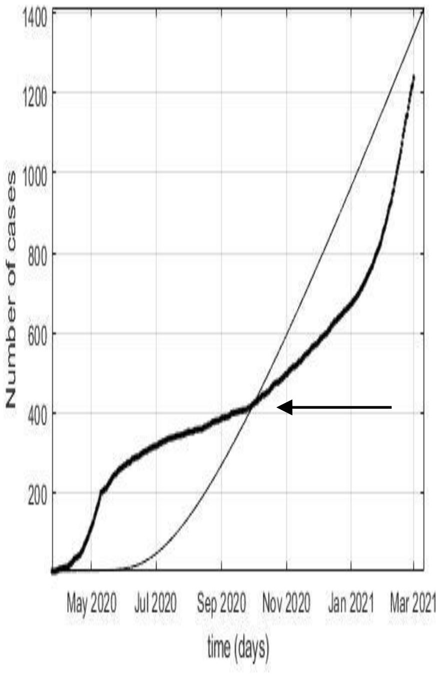
Active



Recovered



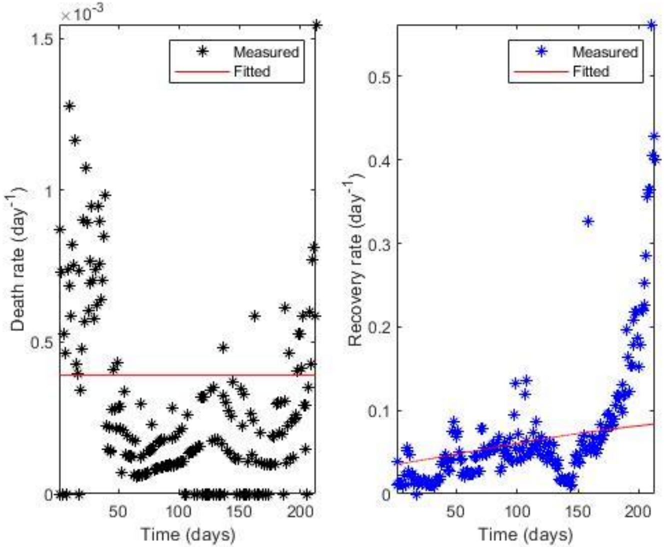
Fatalities



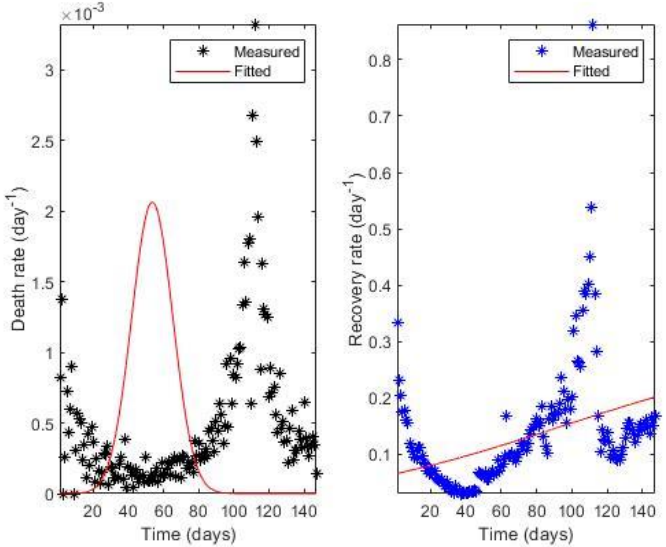
Active (Red)
Recovered (Blue)
Fatalities (Black)

Real Data (**Thick** / Dotted)
SEIRQCD model (Thin line)

1st approach :
Fitting the data for the two waves independently



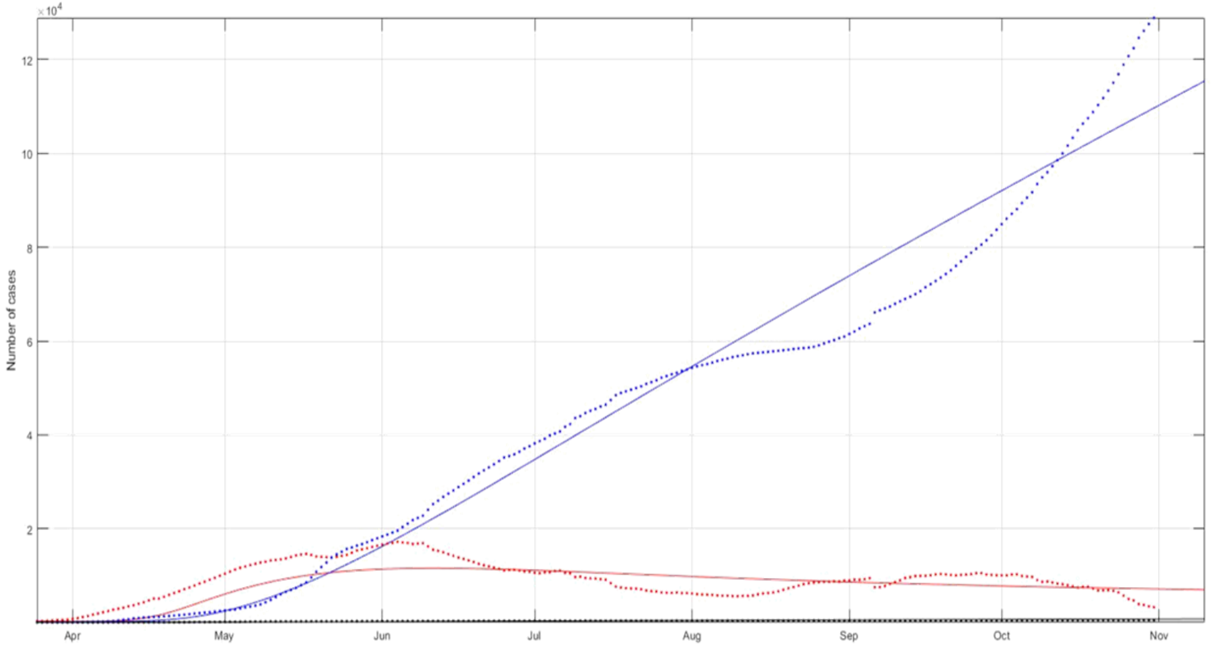
1st of April 2020 to 31st October 2020



1st of November 2020 to 3rd of March 2021

1st wave System Dynamics fitted based on UAE data

(From 1st of April 2020 till to 31st October 2020)

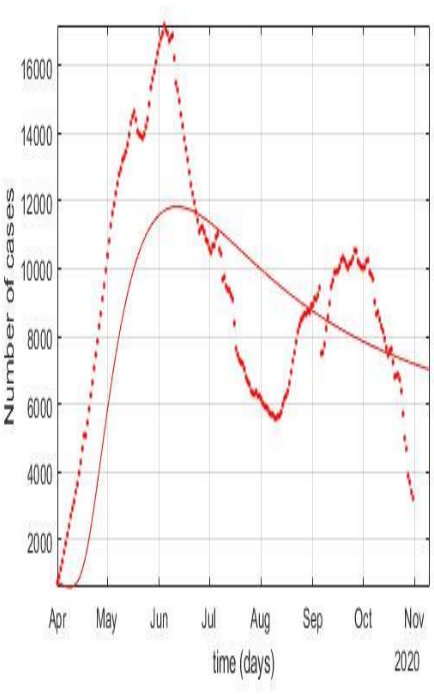


Active (Red)
Recovered (Blue)
Fatalities (Black)

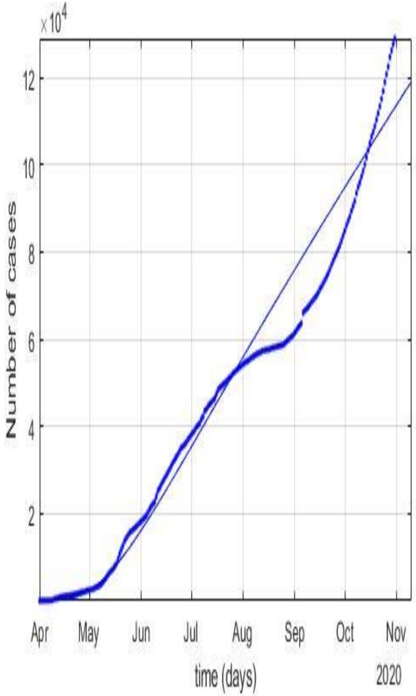
Real Data (**Thick** / Dotted)
SEIRQCD model (Thin line)

System Dynamics (From 1st of April 2020 till 31st of Oct 2021)

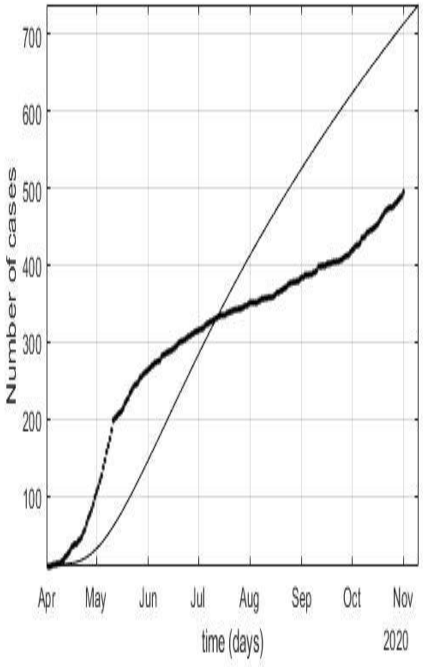
Active



Recovered



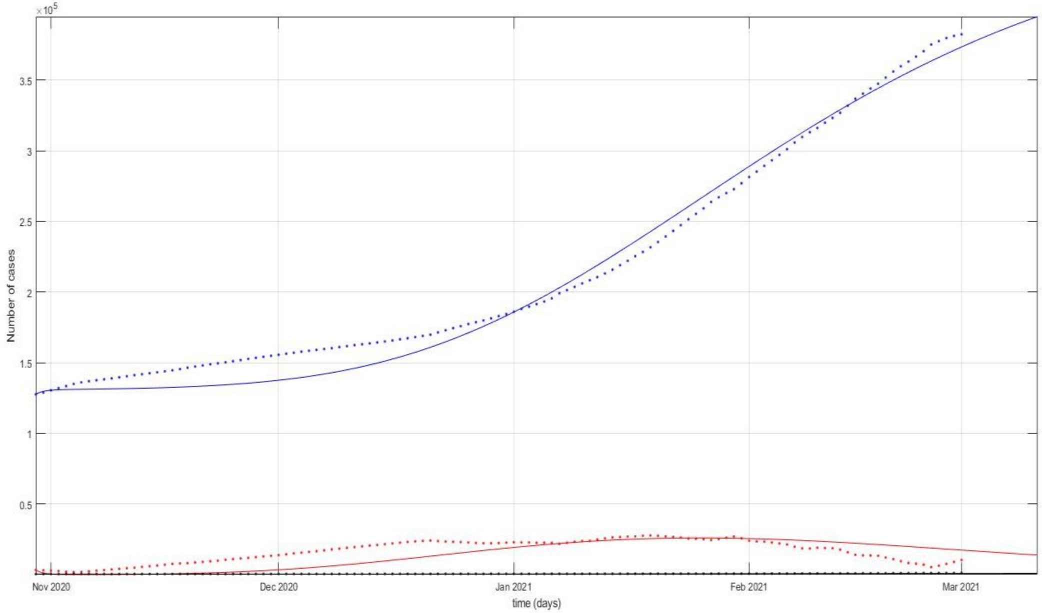
Fatalities



Active (Red)
Recovered (Blue)
Fatalities (Black)

Real Data (**Thick** / Dotted)
SEIRQCD model (Thin line)

2^{nd} wave System Dynamics fitted based on UAE data (From 1^{st} of November 2020 till to 1st March 2021)

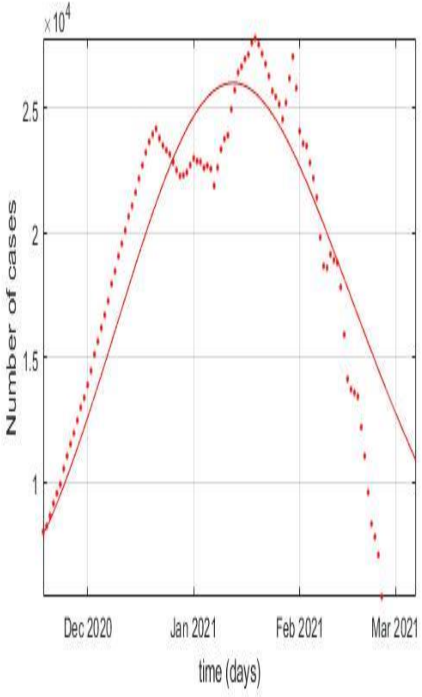


Active (Red)
Recovered (Blue)
Fatalities (Black)

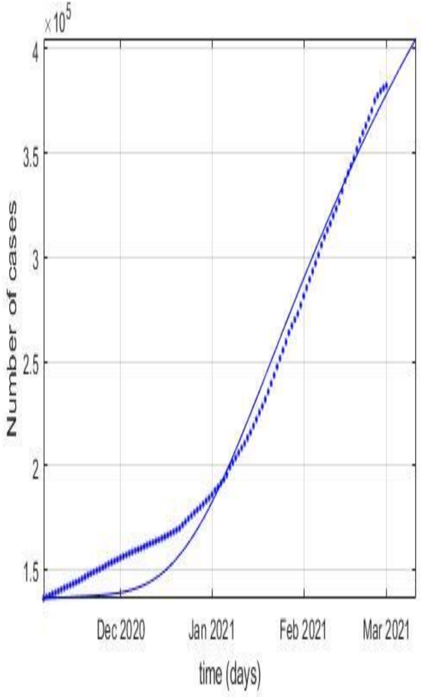
Real Data (**Thick** / Dotted)
SEIRQCD model (Thin line)

System Dynamics (From 31st of Oct 2020 till 1st of Mar 2021)

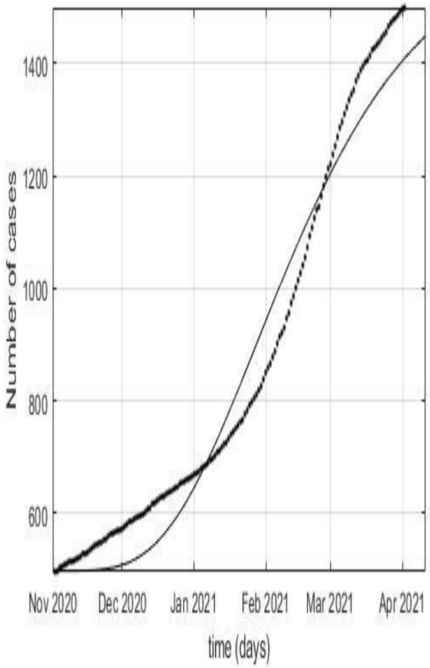
Active



Recovered



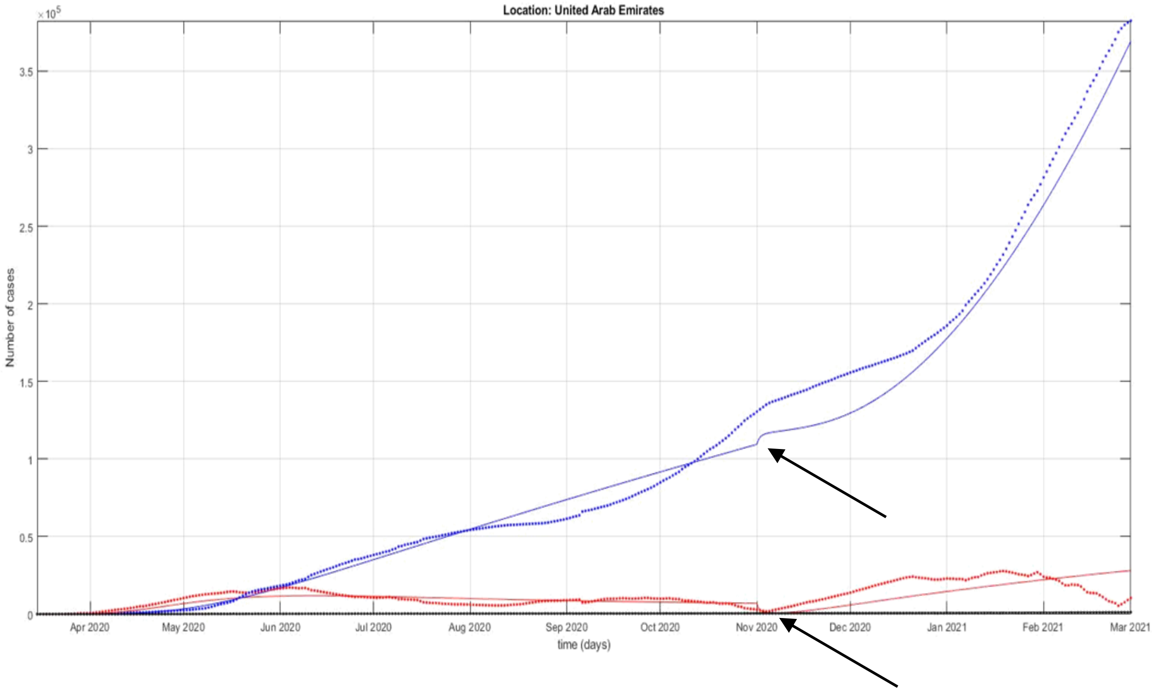
Fatalities



Active (Red)
Recovered (Blue)
Fatalities (Black)

Real Data (**Thick** / Dotted)
SEIRQCD model (Thin line)

2nd Approach:
Display effect of adding 2nd wave (November) UAE



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Recovered (Blue)
Fatalities (Black)

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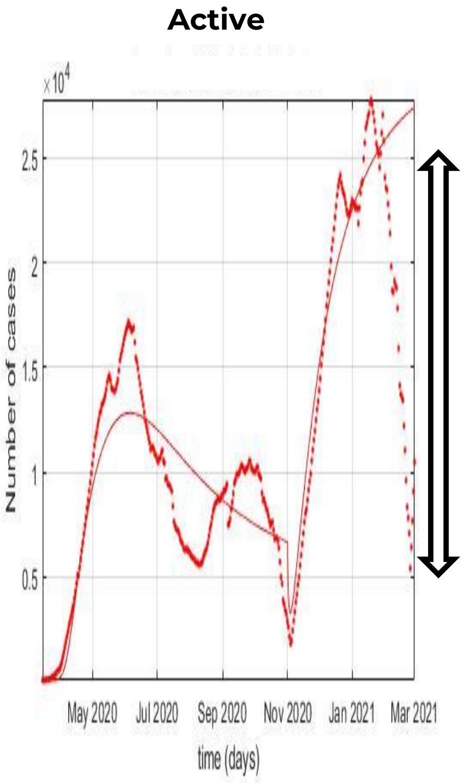
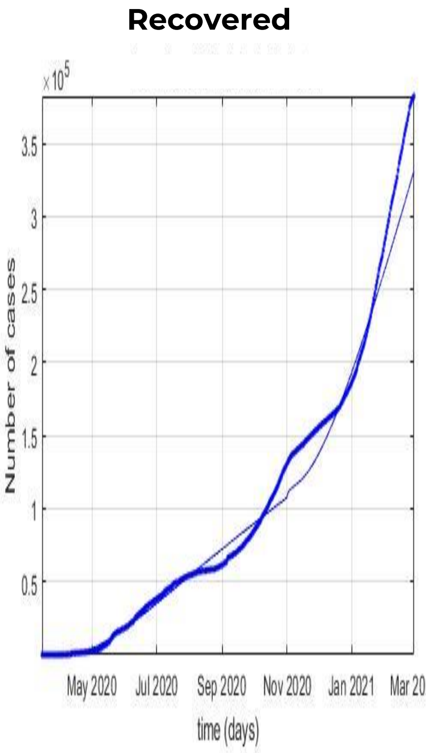
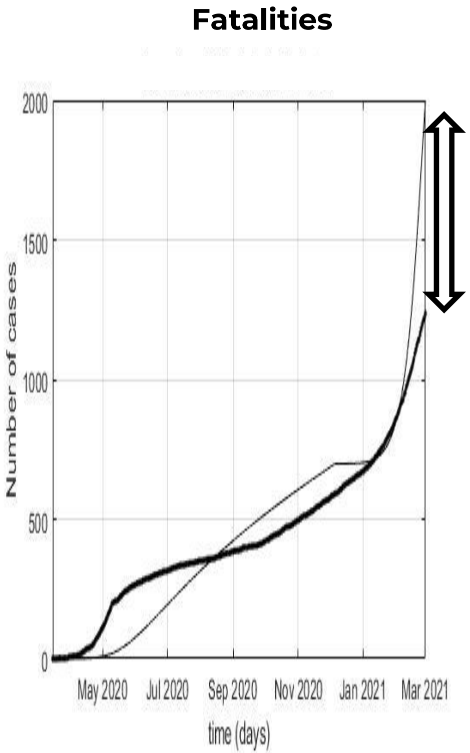
SEIRQCD model (Thin line)

2^{nd} Approach System of Dynamics







Active (Red)
Recovered (Blue)
Fatalities (Black)

Real Data (**Thick** / Dotted)
SEIRQCD model (Thin line)

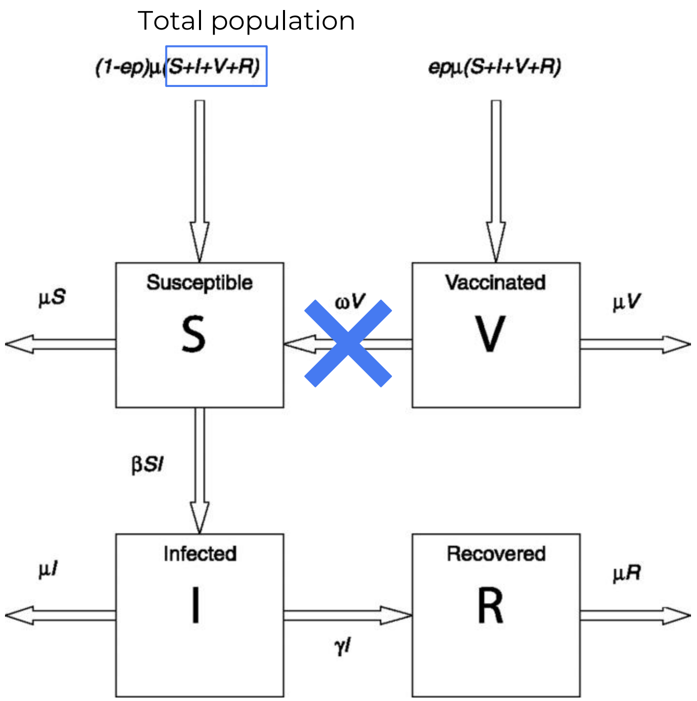
Vaccination model

The vaccination model introduces an extra compartment in addition to the previous compartments. The vaccination model becomes SVIR, and the vaccination compartment is denoted by V(t).

1. Vaccine-induced immunity is life-long.
2. Vaccine-induced immunity wanes with time.

- Total population is fixed in size.
- Natural immunity is assumed to be life-long.

If vaccine induced immunity is life-long, then the SVIR model is:



Parameter	Interpretation
p	Fraction of population vaccinated
e	Fraction of vaccinated population protected by the vaccine for an average period of $\frac{1}{\omega}$ years
μ	Death rate
ω	Rate of loss of vaccine-induced immunity
β	Force of infection (transmission parameter)
γ	Rate of recovery

- Susceptible individuals become infected at rate βI.
- Infectious individuals recover at rate γ to become immune.

1. $$\frac{dS}{dt} = \underbrace{\boxed{(1-ep)\mu N}}^{\text{unvaccinated}} - \overbrace{\boxed{\beta SI}}^{\text{infections}} - \overbrace{\boxed{\mu S}}^{\text{deaths}},$$

2. $$\frac{dV}{dt} = \overbrace{\boxed{ep\mu N}}^{\text{vaccinated}} - \overbrace{\boxed{\mu V}}^{\text{deaths}},$$

3. $$\frac{dI}{dt} = \boxed{\beta SI} - \boxed{\gamma I} - \overbrace{\boxed{\mu I}}^{\text{deaths}},$$

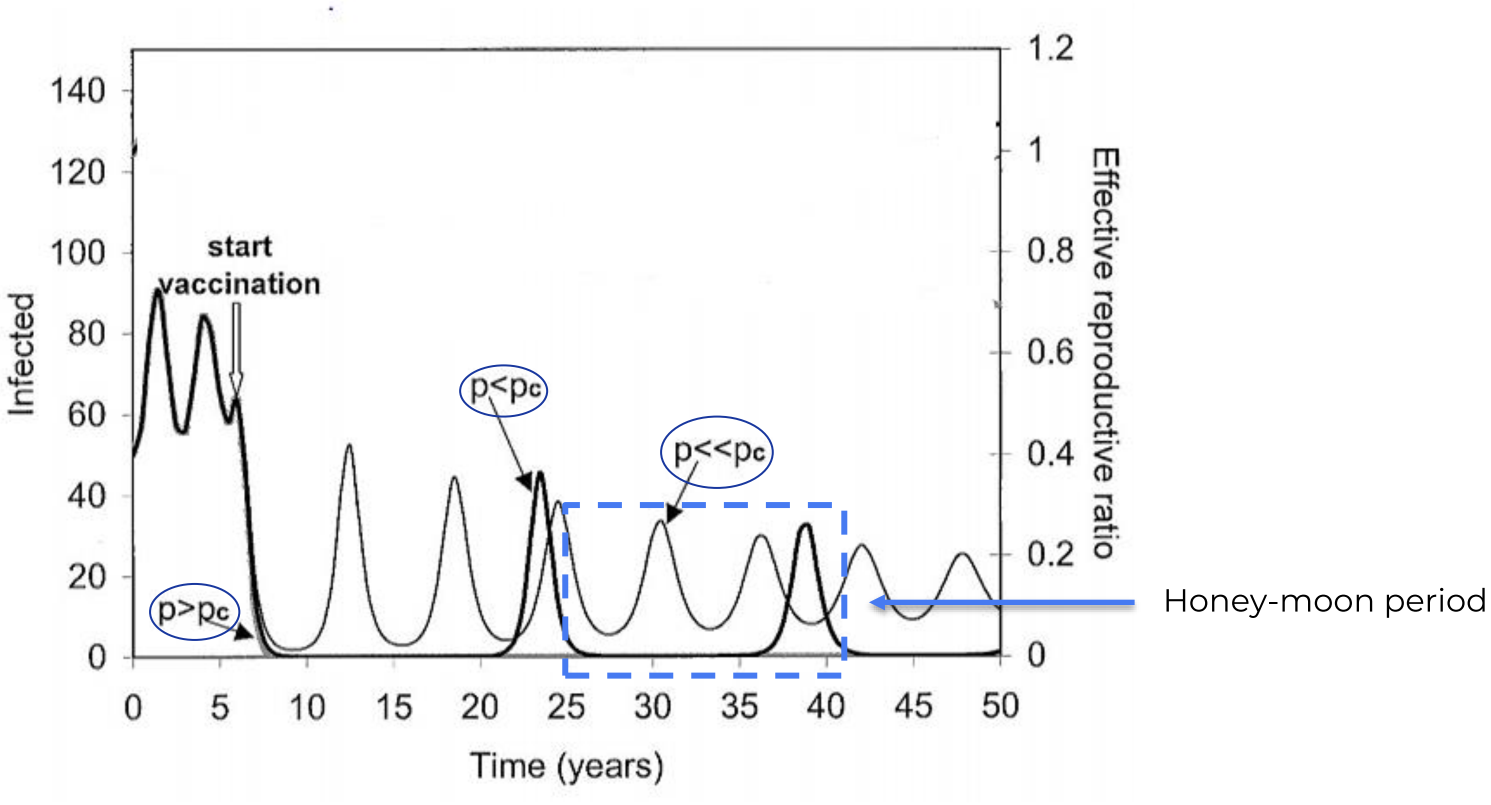
4. $$\frac{dR}{dt} = \overbrace{\boxed{\gamma I}}^{\text{recoveries}} - \underbrace{\boxed{\mu R}}_{\text{deaths}},$$

Parameter	Interpretation
p	Fraction of population vaccinated
e	Fraction of vaccinated population protected by the vaccine for an average period of $\frac{1}{\omega}$ years
μ	Death rate
ω	Rate of loss of vaccine-induced immunity
β	Force of infection (transmission parameter)
γ	Rate of recovery

- In the model we assumed everyone is either susceptible or immune. Therefore, $p + S = 1$.
- The susceptible population will be $1 - p$.
- The new basic reproductive number is $(1 - p)R_0$ with R_0 is the number of secondary cases caused by one primary case introduced into a population that is wholly susceptible.
- The new basic reproductive number is the number of secondary cases caused by one primary case introduced into a population in which a proportion p have been vaccinated.
- For an ideal vaccine, the following equation denotes the proportion at which the vaccination eliminates the infection:

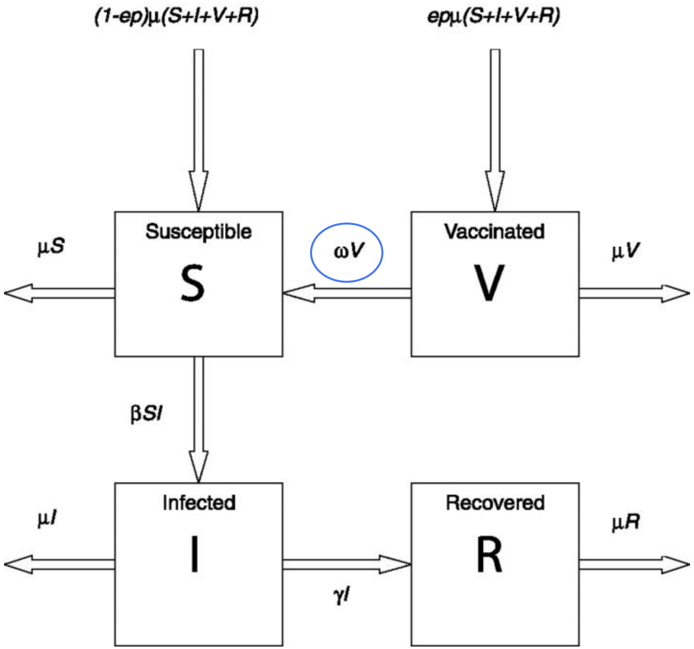
$$p_c = 1 - \frac{1}{R_0}$$

- If the target coverage of eradication is below p_c% then the eradication is not achieved.



Modelling wanning immunity

The transition include the possibility that vaccinated individuals will eventually pass into the susceptible class as their vaccine-induced immunity fails.



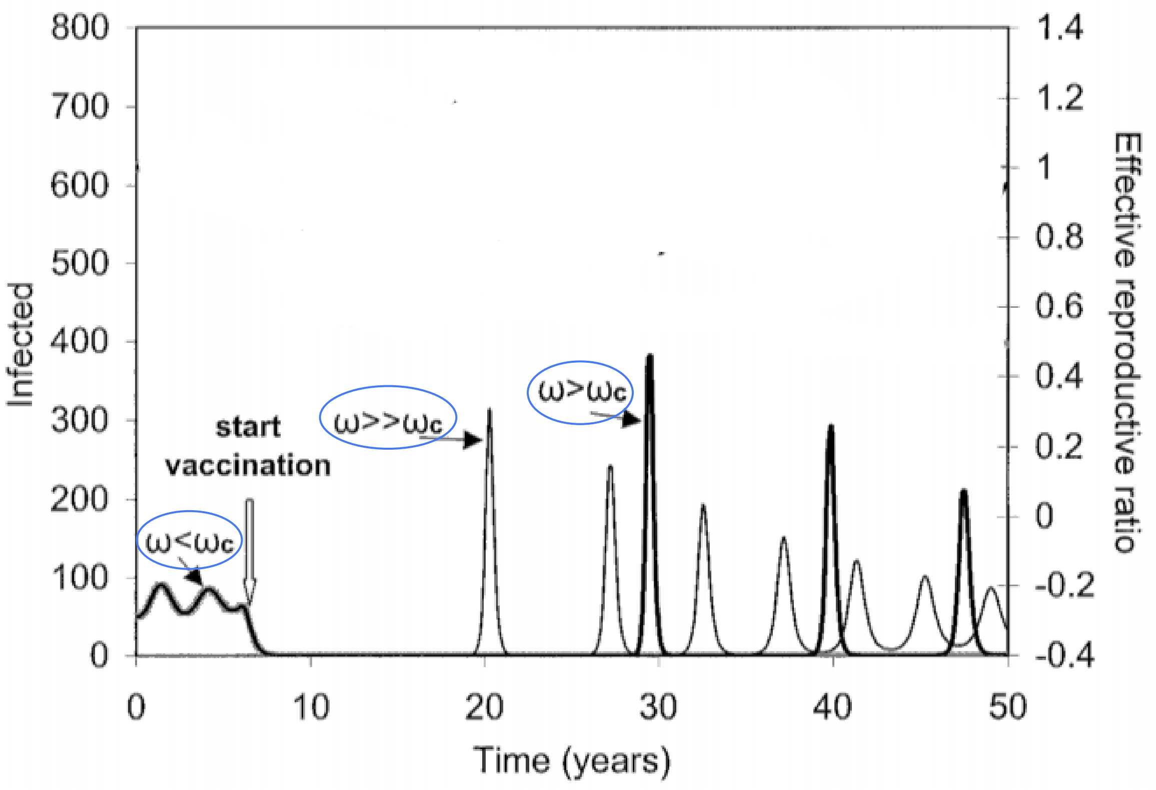
$$\frac{dS}{dt} = (1 - ep)\mu N - \beta SI - \mu S \boxed{+ \omega V,}$$

$$\frac{dV}{dt} = ep\mu N - \mu V \boxed{- \omega V,}$$

$$\frac{dI}{dt} = \beta SI - \gamma I - \mu I,$$

$$\frac{dR}{dt} = \gamma I - \mu R,$$

If vaccine-induced immunity wanes faster than this critical rate, then eradication will not be achieved.



Discussion

1 The assumptions taken for this model effected the reliability of our results

But how can this be addressed in future iteration of our work

Modified SEIR prediction model:

$$\frac{dS(t)}{dt} = -\alpha S(t) - \beta \frac{S(t)I(t)}{N_{pop}}$$

$$\frac{dE(t)}{dt} = -\gamma E(t) + \beta \frac{S(t)I(t)}{N_{pop}}$$

$$\frac{dI(t)}{dt} = \gamma E(t) - \delta I(t) \boxed{-\kappa(t)I(t) - \lambda(t)I(t)}$$

$$\frac{dQ(t)}{dt} = \delta I(t) - \lambda(t)Q(t) - \kappa(t)Q(t)$$

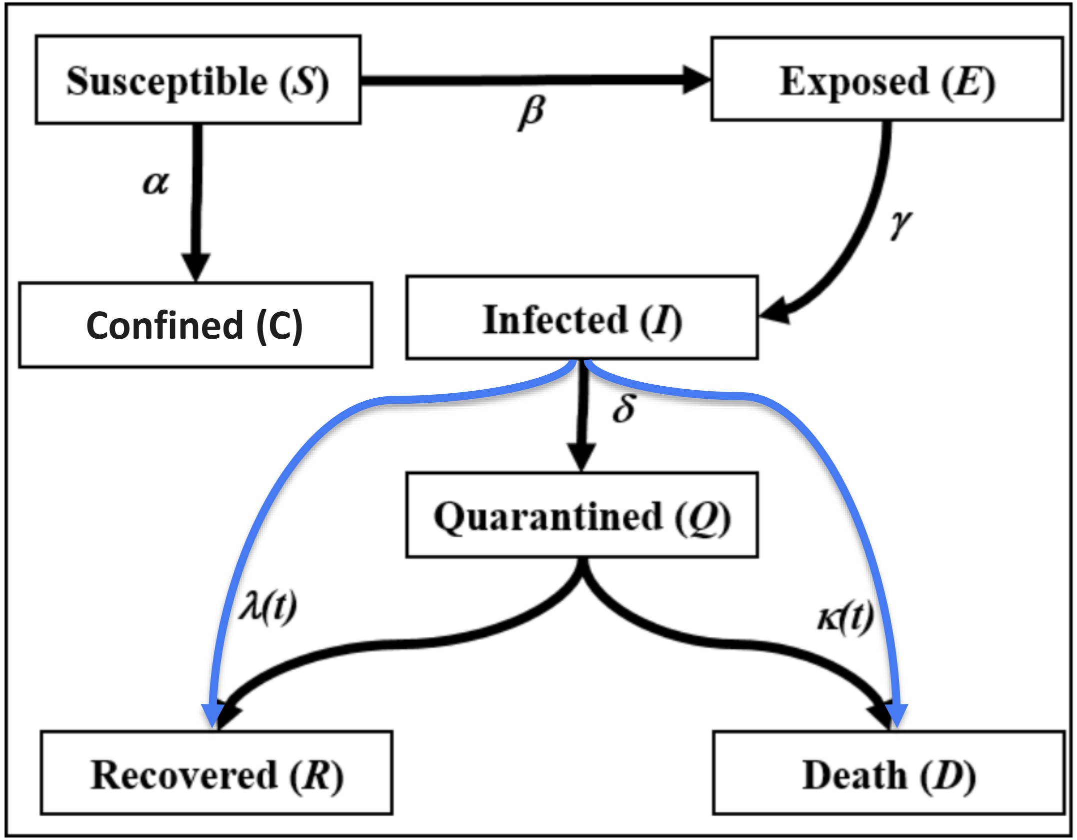
$$\frac{dR(t)}{dt} = \lambda(t)Q(t) \boxed{+\lambda(t)I(t)}$$

$$\frac{dD(t)}{dt} = \kappa(t)Q(t) \boxed{+\kappa(t)I(t)}$$

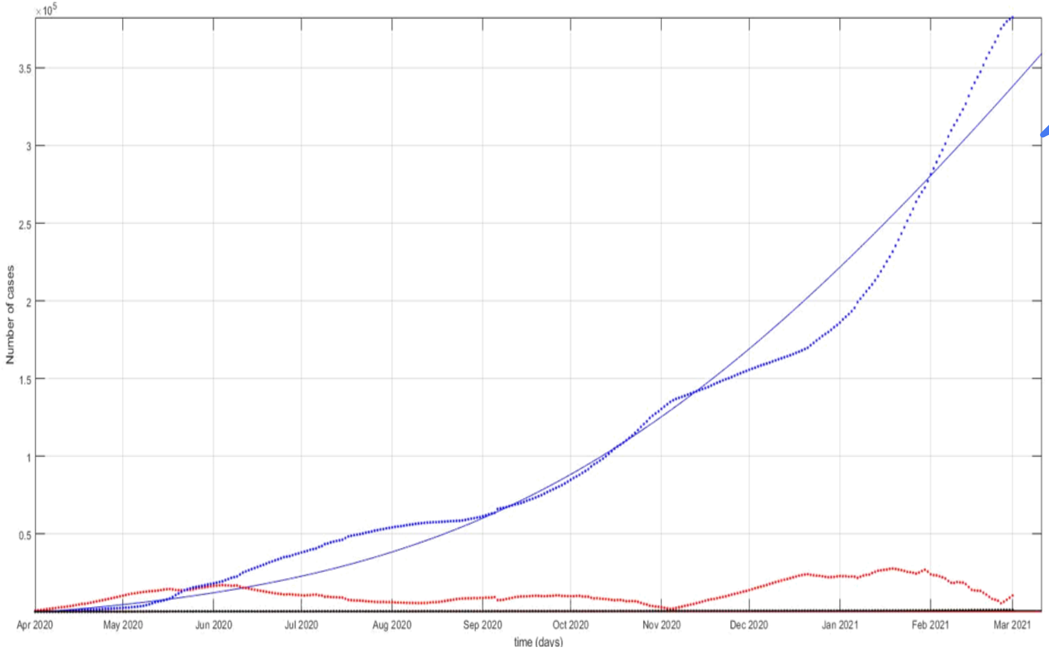
$$\frac{dC(t)}{dt} = \alpha S(t)$$

Table 1: Main Model Parameter

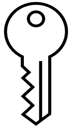
Parameter	Description
α	Protection parameter
β	Transmission parameter
γ	Recovery parameter
δ	Rate at which people enter in quarantine
$\lambda(t)$	Time-dependant recovery rate
$\kappa(t)$	Time-dependant mortality rate


Susceptible (S)
Exposed (E)
β
α
γ
Confined (C)
Infected (I)
δ
Quarantined (Q)
λ(t)
κ(t)
Recovered (R)
Death (D)

Updated model



Better fit



Active (Red)
Recovered (Blue)
Fatalities (Black)

Real Data (**Thick** / Dotted)
SEIRQCD model (Thin line)

DISCUSSION

2 Our model underestimated the cases prediction since it didn't take into consideration the death rate and recovery rate of infectious individuals

3 Due to lack of data on cases for each age groups and over complexity of our model introduced last time we couldn't combine both models .

4 The modified SEIR model failed to capture Vaccination effect and thus our analysis on COVID-19 dynamics will be improved when a vaccination is introduced.to the model .

DISCUSSION

5 The assumption that vaccine-induced immunity will give life-long protection is very strong. If it is not true, then many of the calculations about coverage levels for eradication will turn out to be over-optimistic.

6 The model can be more realistic by lifting the assumptions.

7 One can study the other reasons behind not achieving eradication.

8 A more accurate representation for the SVIR can be taken by taken different death rate μ for the different compartments