DRP AM-7

Modelling the COVID-19 pandemic

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Outline

Introduction

- Background
- Model Framework
- Model Equations/Parameters

Results

- Waning Immunity + Reinfection
- Vaccination Effects
- Multiple Variants

Conclusion

- Strengths
- Limitations
- Future work

Background and Objective

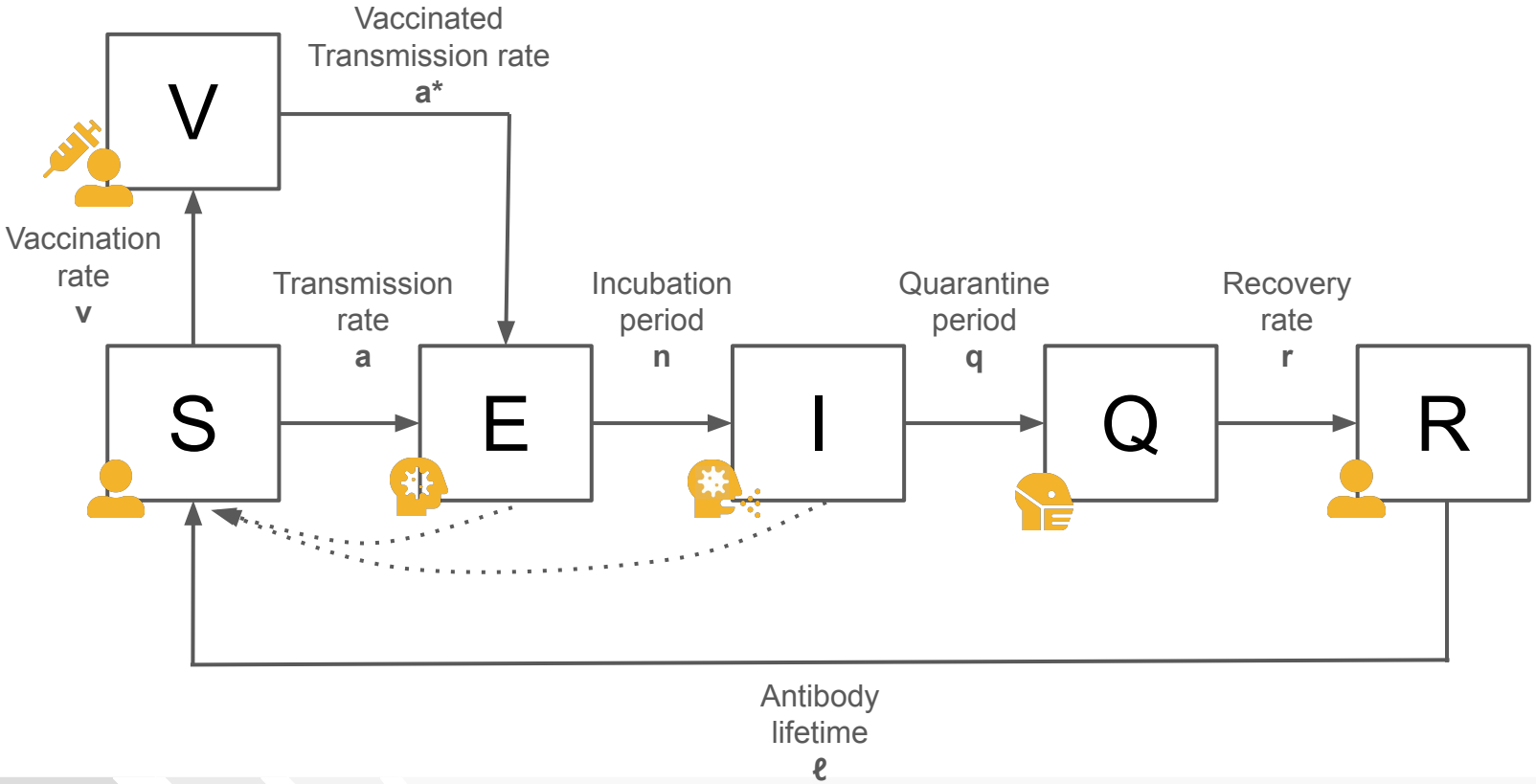
Objective: Studying the impact of vaccination, immunity, and different variants on a global pandemic.

Background:

- COVID-19 created large-scale health and social disruption worldwide, and its spread is shaped by changing infection, recovery, vaccination, and immunity patterns
- Linear ODE modeling captures complex disease dynamics by tracking population flows between disease states

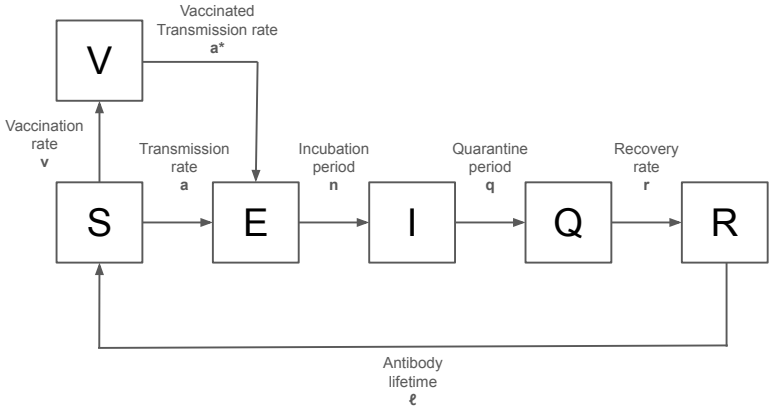
Model Framework

Model Framework



Parameters

Parameter	Definition	Value
a	transmission rate (a_v for vaccinated)	$\frac{R_0 r}{S_0}$
v	vaccination rate	Varies
n	incubation rate	$\frac{1}{7}$
q	quarantine rate	$\frac{1}{14}$
r	recovery rate	$\frac{1}{14}$
l	antibody deterioration rate	$\frac{1}{90}$



Variant	Alpha	Beta	Delta	Gamma	Omicron
R_0	1.143	1.101	1.177	1.115	1.559

Equations

Susceptible S

$$\frac{dS}{dt} = \underbrace{-aS(E+I)}_{\text{become exposed}} + \underbrace{lR}_{\text{return from recovered}} + \underbrace{(-vS)}_{\text{vaccination loss}}$$

Vaccinated V

$$\frac{dV}{dt} = \underbrace{vS}_{\text{vaccination gain}} - \underbrace{a_v(aVE + aVI)}_{\text{exposed despite vaccination}}$$

Exposed E

$$\frac{dE}{dt} = \underbrace{aS(I+E)}_{\text{exposure from susceptibles}} + \underbrace{(-nE)}_{\text{progression to infected}} + \underbrace{a_v(aV(E+I))}_{\text{exposure among vaccinated}}$$

Infected I

$$\frac{dI}{dt} = \underbrace{nE}_{\text{becoming infected}} + \underbrace{(-qI)}_{\text{to quarantine}}$$

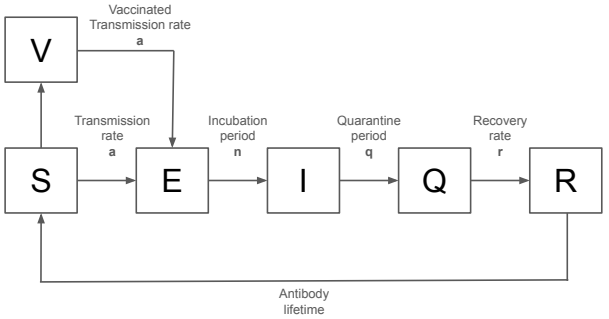
Quarantined Q

$$\frac{dQ}{dt} = \underbrace{qI}_{\text{enter quarantine}} + \underbrace{(-rQ)}_{\text{recovery from quarantine}}$$

Recovered R

$$\frac{dR}{dt} = \underbrace{rQ}_{\text{recovery from quarantine}} + \underbrace{-lR}_{\text{loss of immunity}}$$

- Negatives imply people leaving the group
- Positives imply entering the group



Results

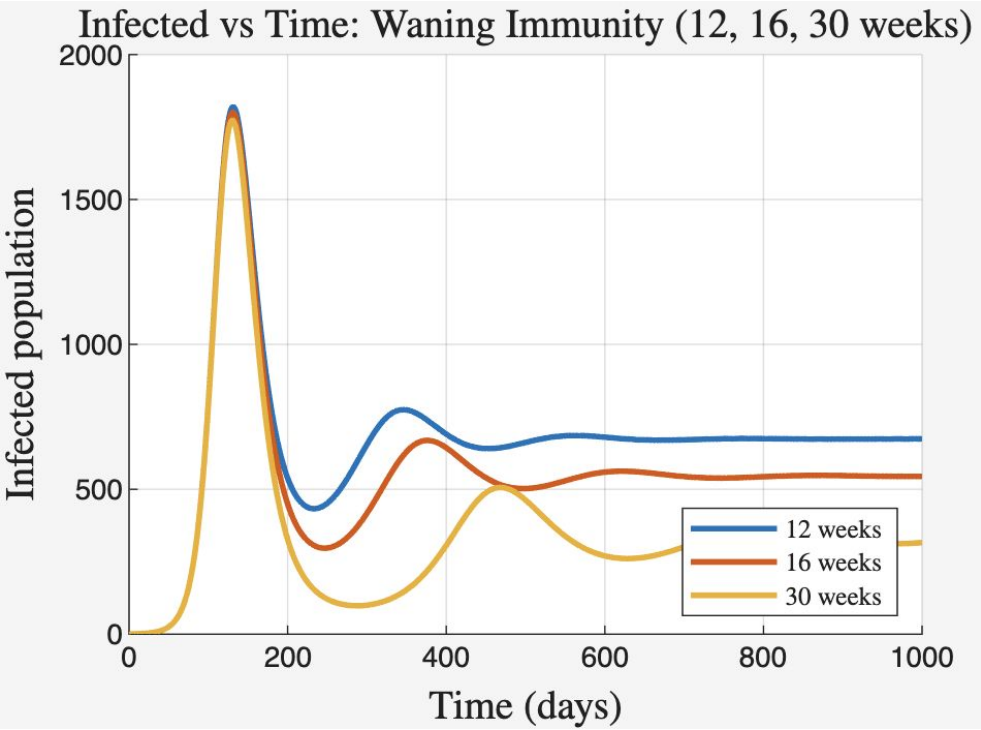
Waning Immunity (R⟶ S)

ℓ = antibody deterioration rate (R⟶S)

Tested immunity durations:

- ℓ = 1/84 ≈ 12 weeks immunity
- ℓ = 1/112 ≈ 16 weeks immunity
- ℓ = 1/210 ≈ 30 weeks immunity

Infection I(t)

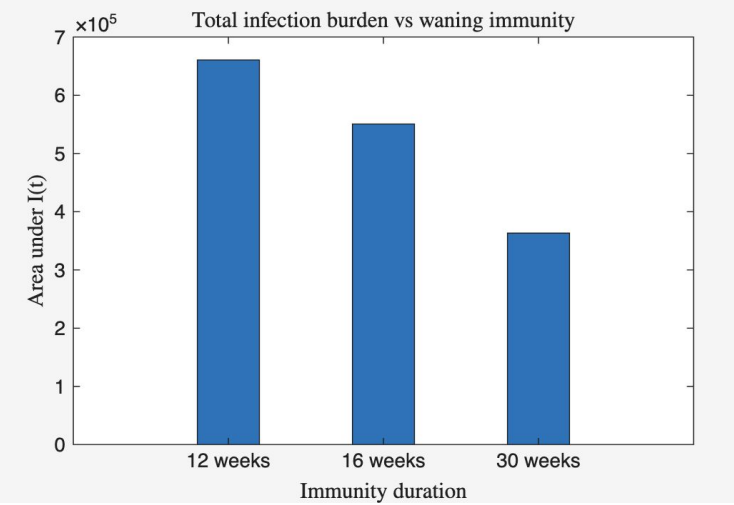


Key observations:

- 30 weeks (yellow): Sharp single wave
- 16 weeks (red): Broader, higher baseline
- 12 weeks (blue): Largest peak (1820), sustained transmission

Total Epidemic Size

Immunity duration	I value	Peak I	Peak time	AUC (total infections)
12 weeks	0.01190	1820.3	131 days	660,614
16 weeks	0.00893	1801.7	131 days	550,618
30 weeks	0.00476	1774.2	130 days	363,242



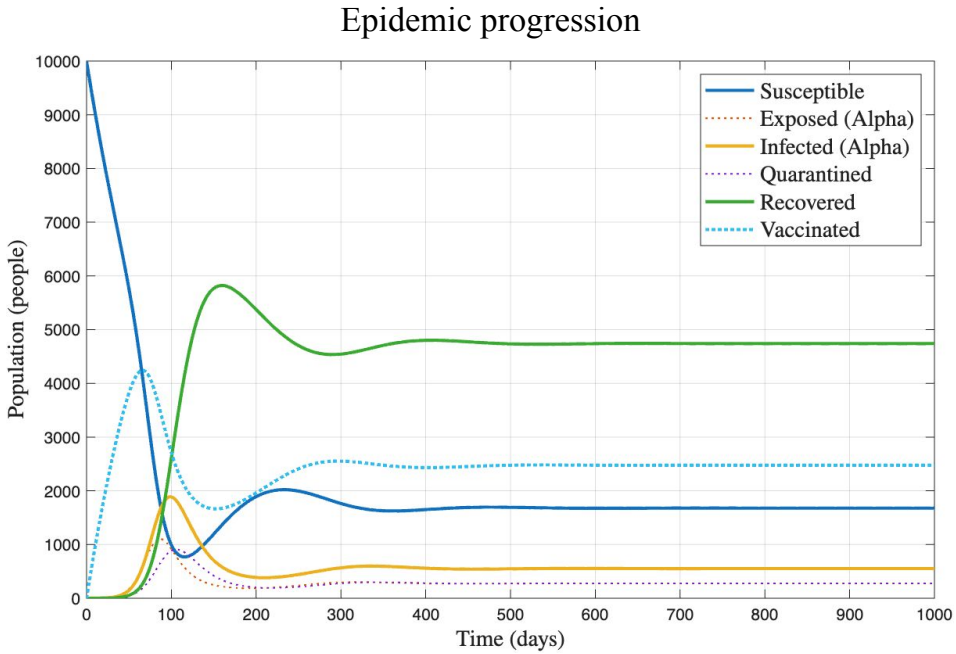
Key observation: 12-week immunity creates 1.8x larger epidemics

SEIQRV

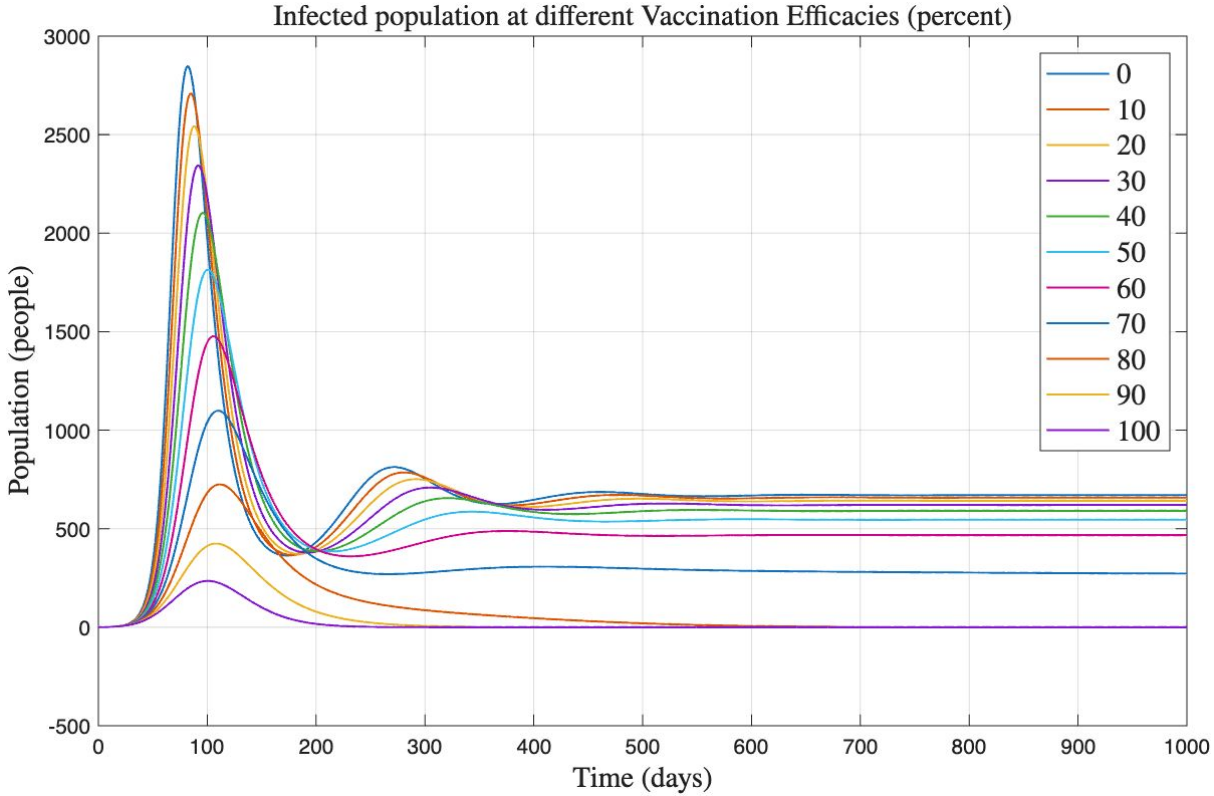
Susceptible Exposed Infected Quarantined Recovered Vaccinated

What are we looking at?

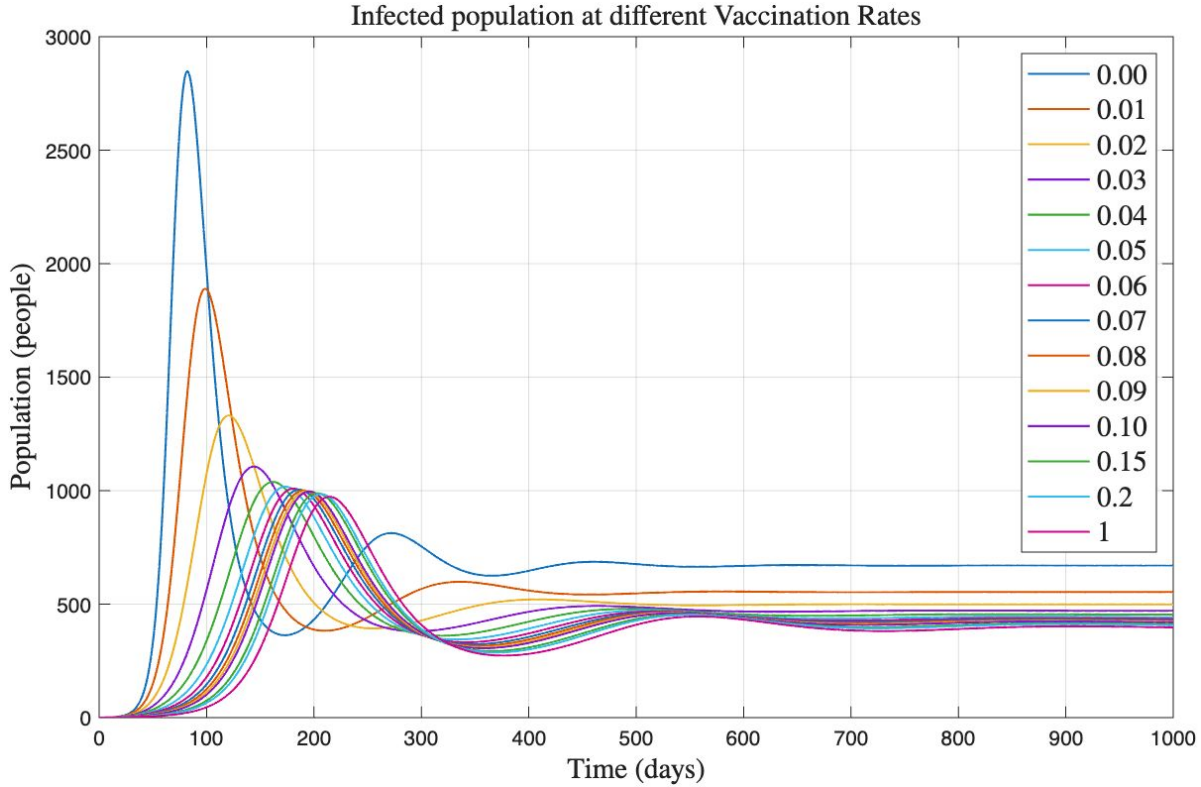
- **Vaccine efficacy:** reduced transmission
  - Different efficacy rates (how much transmission is reduced)
- **Vaccination rate:**
  - Different vaccination rates



Vaccination Efficacy



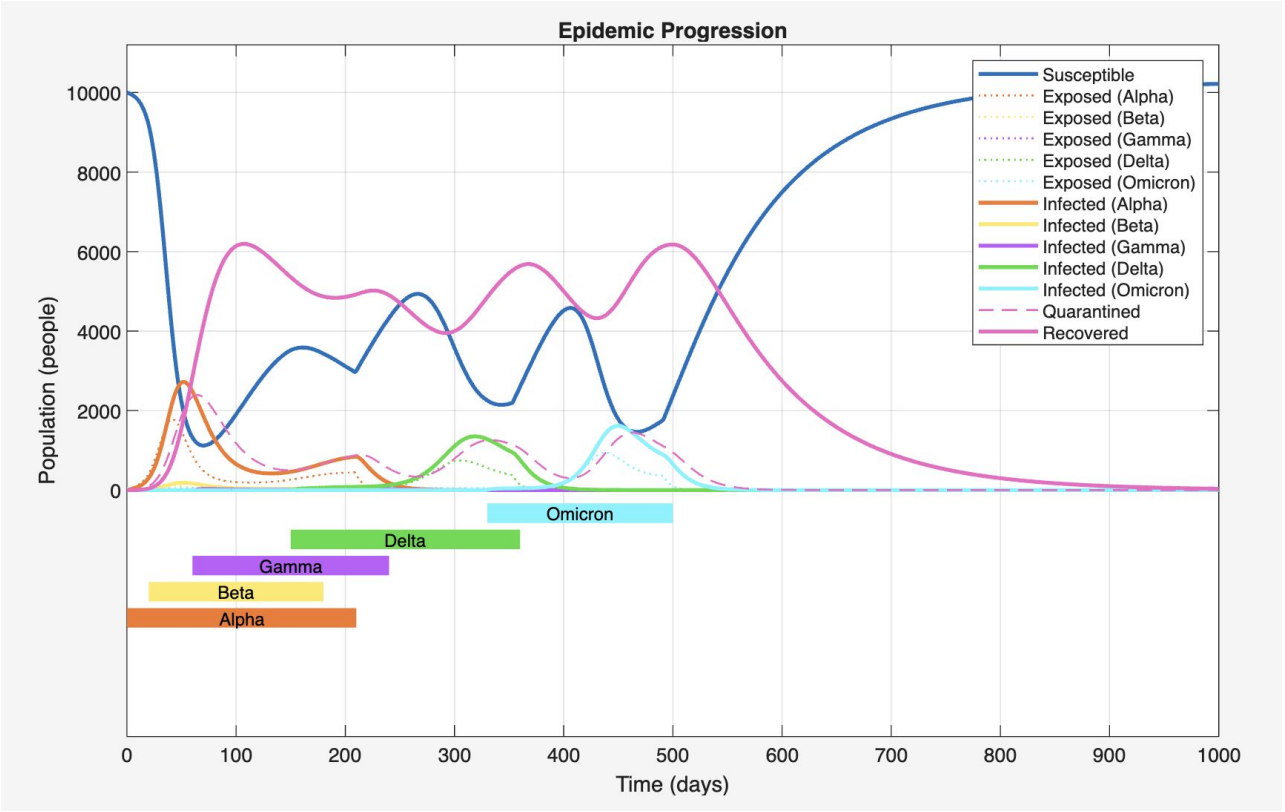
Vaccination Rate

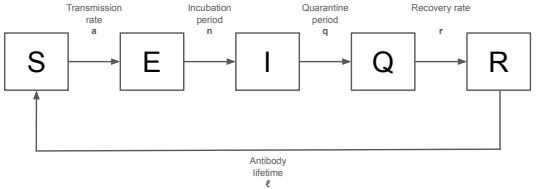


SEIQR (+ Variants)

Susceptible Exposed Infected Quarantined Recovered

Results - COVID Variants





- Alpha, Beta, Gamma, Delta, Omicron Variants
- Drops in susceptible population → peaks in infected groups

Conclusion

Strengths

- Projection of disease progression
- Can see how different interventions affect epidemic in a “controlled” environment
  - Tells us what to prioritize
  - e.g. Vaccination: prioritize efficacy over rate

Limitations

Model assumptions

- Fixed population: N = 10,000 (no deaths/births) but COVID mortality + natural demographics change susceptibility
- Everyone follows S → E → I → Q → R → S exactly, but there are asymptomatic cases, misdiagnosis, treatment failures

Linear ODE assumptions

- No travel, superspreaders, regional outbreaks
- No behavioural changes (lockdowns, testing, masks)
- Single homogeneous population "box"

Future Work

Opinion dynamics

Human behaviour

Closure

Thank you!

Questions?

References

Manathunga, S. S., Abeyagunawardena, I. A., & Dharmaratne, S. D. (2023). A comparison of transmissibility of SARS-CoV-2 variants of concern. *Virology journal*, *20*(1), 59. https://doi.org/10.1186/s12985-023-02018-x

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