DRP AM-7

Modelling the COVID-19 Pandemic

Speakers: Aster Huang, Katherine Chambers, Lily Li
Mentor: Betty Zhang

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Background and Objective

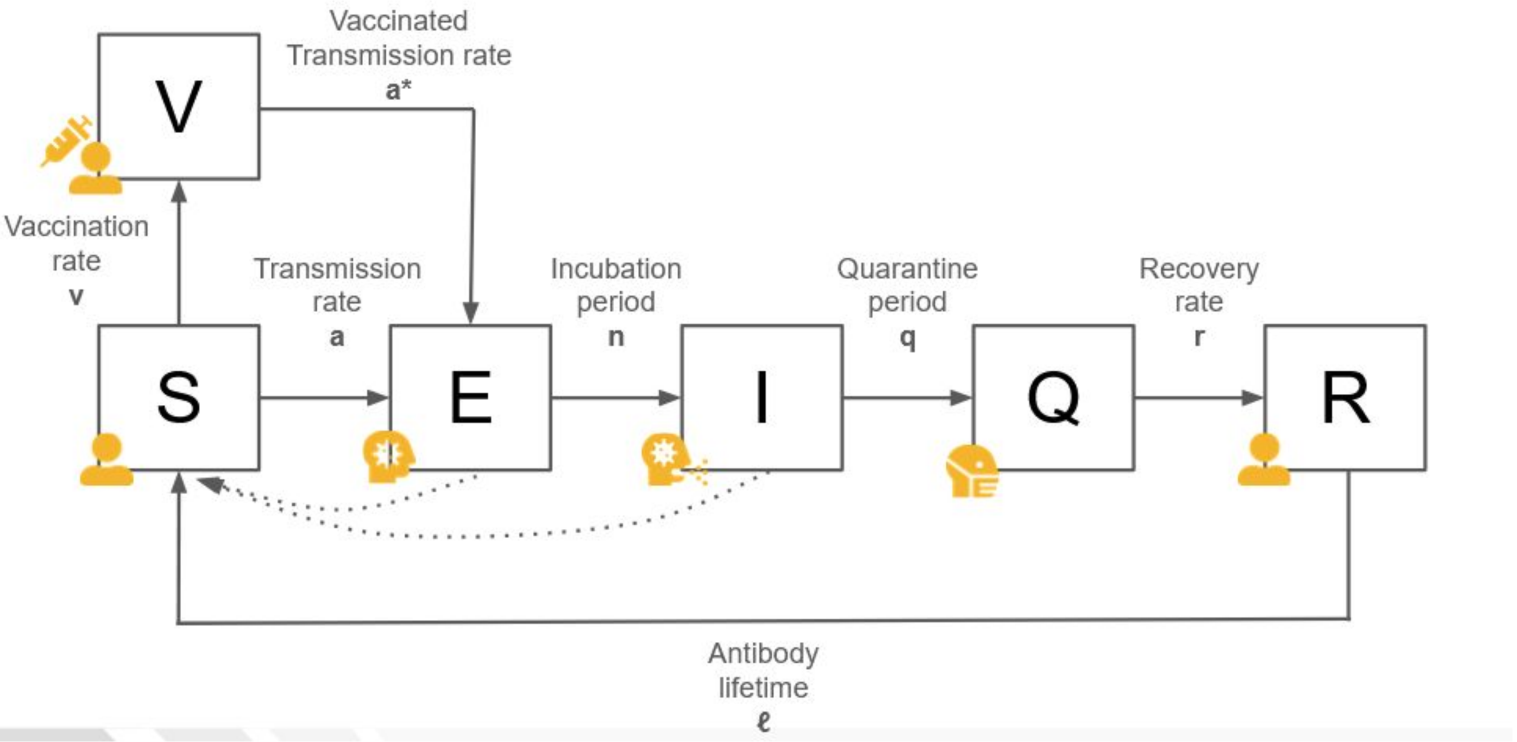
Background:

Global Epidemiological Pressure: Increasing frequency of worldwide **infectious disease outbreaks** amidst global **population growth**

Need for Advanced Frameworks: Traditional models require robust coping mechanisms to capture complex, **real-world** transmission dynamics and healthcare burdens

Objective: Develop advanced **stochastic** and **agent-based** modeling frameworks to simulate real-world COVID-19 transmission, **vaccination rollouts**, and future epidemic trends for public health policy

Deterministic Model

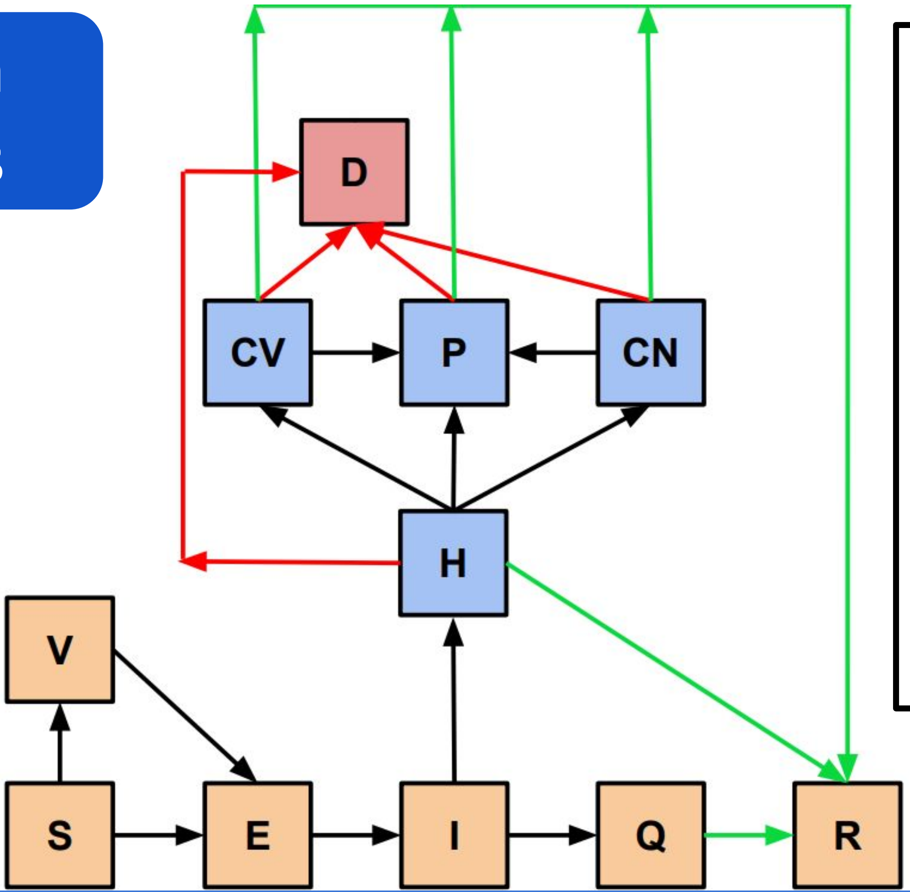


Hospitalization Compartments

Clinical Progression

Arrows Legend:
Black - Disease Progression
Green - Recovery
Red - Mortality

Disease Progression



Compartment Legend:

H → Hospital Ward
CV→ ICU with Ventilator
CN → ICU without Ventilator
P → In-Patient Care
D → Death

Clinical Progression Parameters

Parameters:	Meaning:	Compartment Movement
h_{eff}	Hospitalization Rate	$[I] \Rightarrow [H]$
g_h, d_h	Hospital Discharge & Mortality	$[H] \Rightarrow [D]\|[R]$
m_v, m_n	ICU Admission Rates	$[H] \Rightarrow [C_v]\|[C_n]$
g_c, d_c	ICU Recovery and Mortality	$[C_n][C_v] \Rightarrow [D]\|[R]$
p_h, p_c	In-Patient Transition Rates	$[H][C_n][C_v] \Rightarrow [P]$
g_p, d_p	In-Patient Discharge and Mortality	$[P] \Rightarrow [D]\|[R]$

ODE Structure

Two Main Rules:	**Inflow & Outflow**	**Interactions**
	Positive Terms → Inflow Negative Terms → Outflow	Compartment populations are multiplied

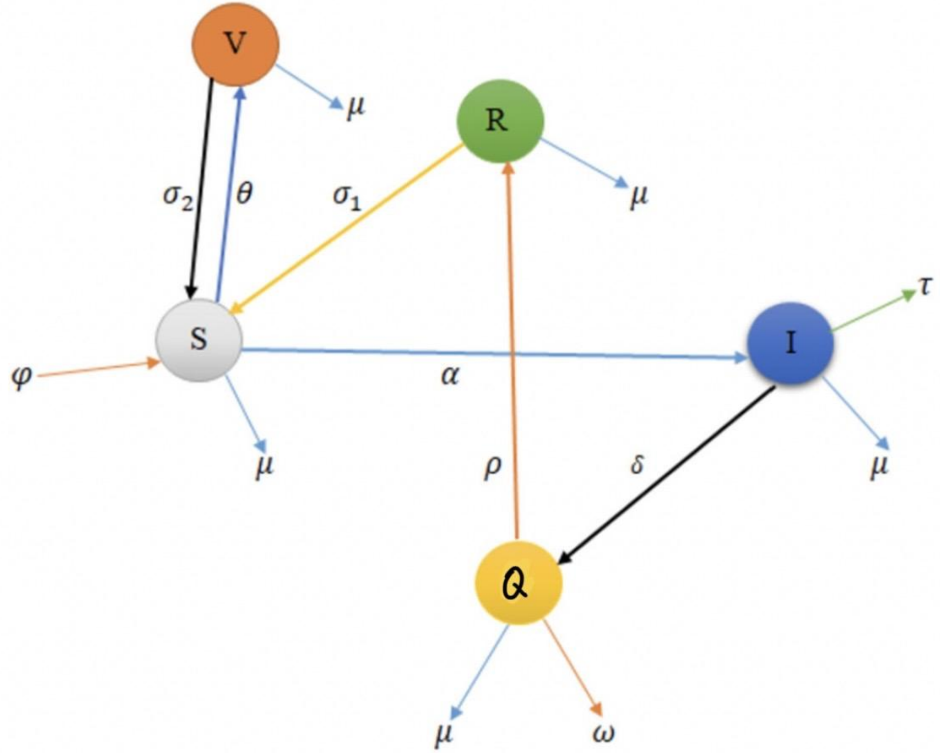
Examples:	
In Patient Care Facilities:	$$\frac{dP}{dt} = p_h H + p_c(CV + CN) - (d_p + g_p)P$$
To Exposed From Susceptible & Vaccinated	$$\frac{dE}{dt} = aSI + a^* VI - bE$$

Stochastic model

Key Differences from Original Model

Instant Transmissibility: Omits the exposure phase (E); individuals become infectious immediately upon contact (S⟶I).

Direct Immunity Decay: Individuals losing vaccine immunity return directly to the Susceptible state (V⟶S).



Stochastic model

Stochastic Noise & Randomness

Standard Noise (Y=X+ε): Adds a simple, static error term to a deterministic model

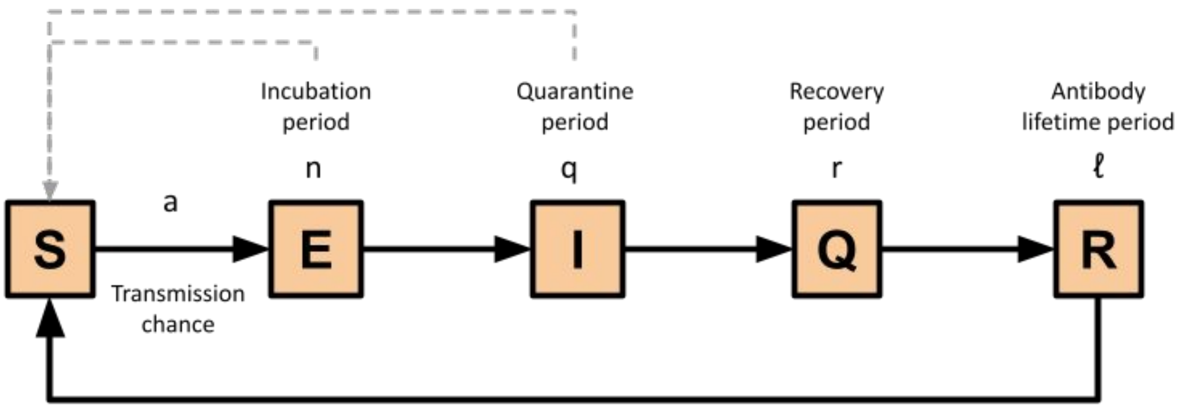
Our Approach: Integrates **Brownian motion** to dynamically capture real-world continuous randomness

$$\begin{cases} dS(t) = (\varphi + \sigma_1 R(t) + \sigma_2 V(t) - (\alpha I(t) + \theta + \mu)S(t))\,dt + \beta_1 S(t)\,\boxed{dB_1(t),} \\ dV(t) = (\theta S(t) - (\mu + \sigma_2)V(t))\,dt + \beta_2 V(t)\,\boxed{dB_2(t),} \\ dI(t) = (\alpha S(t)I(t) - (\mu + \delta + \tau)I(t))\,dt + \beta_3 I(t)\,\boxed{dB_3(t),} \\ dT(t) = (\delta I(t) - (\mu + \rho + \omega)T(t))\,dt + \beta_4 T(t)\,\boxed{dB_4(t),} \\ dR(t) = (\rho T(t) - (\mu + \sigma_1)R(t))\,dt + \beta_5 R(t)\,\boxed{dB_5(t),} \end{cases}$$

$$\Delta W_i = \sqrt{\Delta t} Z_{i+1} \iff \texttt{dW1} = \texttt{sqrt(dt)} * \texttt{randn();}$$

Agent based model (ABM)

Highlight: Each agent acts independently and have randomized interactions with other agents.



Parameter	Meaning	Value
a	Transmission chance	33%
n	Incubation period	2-7 days
q	Quarantine period	0-14 days
r	Recovery period	10-14 days
ℓ	Antibody lifetime period	80-90 days

Attributes of an agent

Agent

- Status
- Movement rules
- Human behaviour
- Randomized parameters

Status:

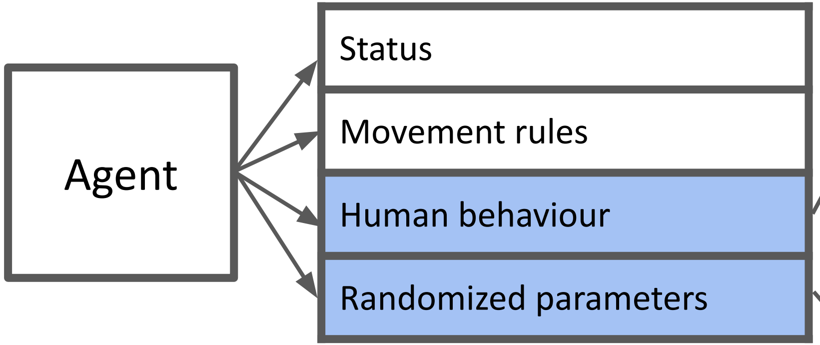
0 1 2 3 4

S . E . I . Q . R

Movement rules:

1. Environment space → **fixed** number of agents
2. Agent can move within a certain **radius**
3. Agent will avoid **large gatherings**

Attributes of an agent



Human behaviour:

Mandate: **decrease** interactions between agents and infection chance

Compliance: agent can decide if they will follow the **mandate**.

Randomized parameters:

Agents choose how long they will stay in a compartment.

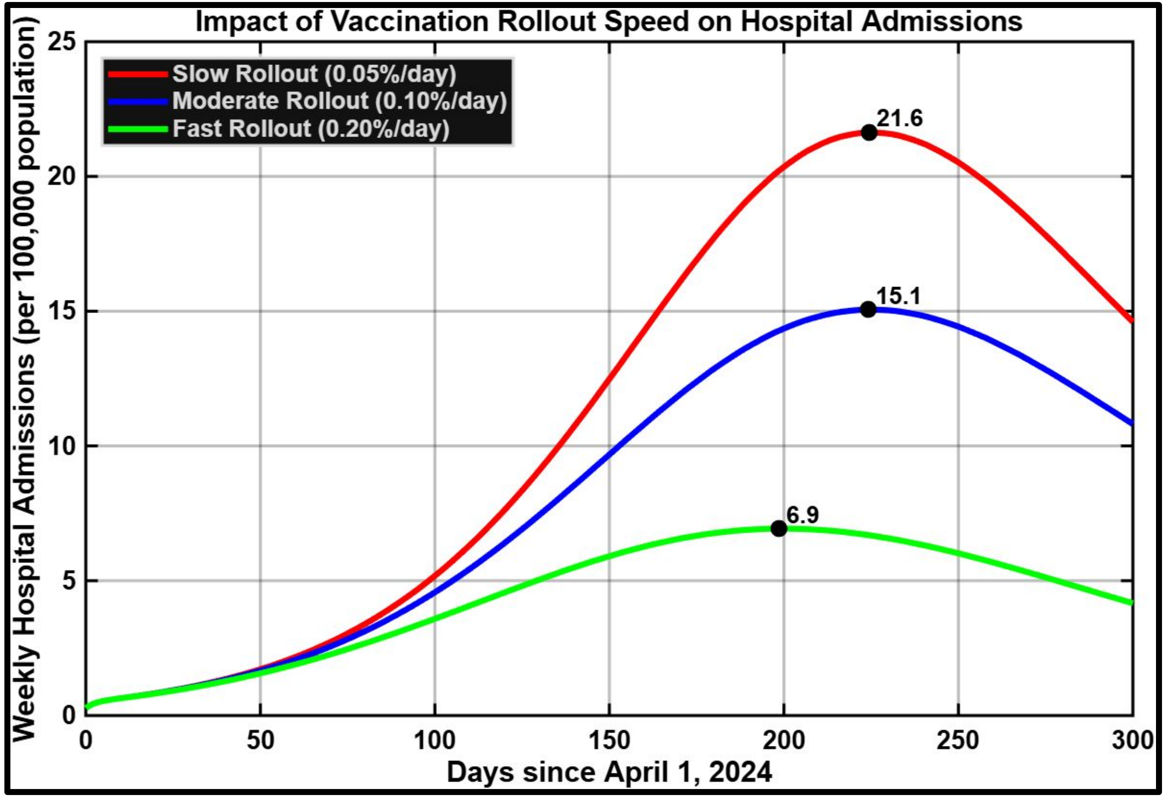
Results

Daily Vaccination Rate on Hospital Admissions

Parameter → vr

- Daily Vaccination Rate

- **Slow rollout**: 0.05% of population/day
- **Moderate rollout**: 0.10% of population/day
- **Fast rollout**: 0.20% of population/day



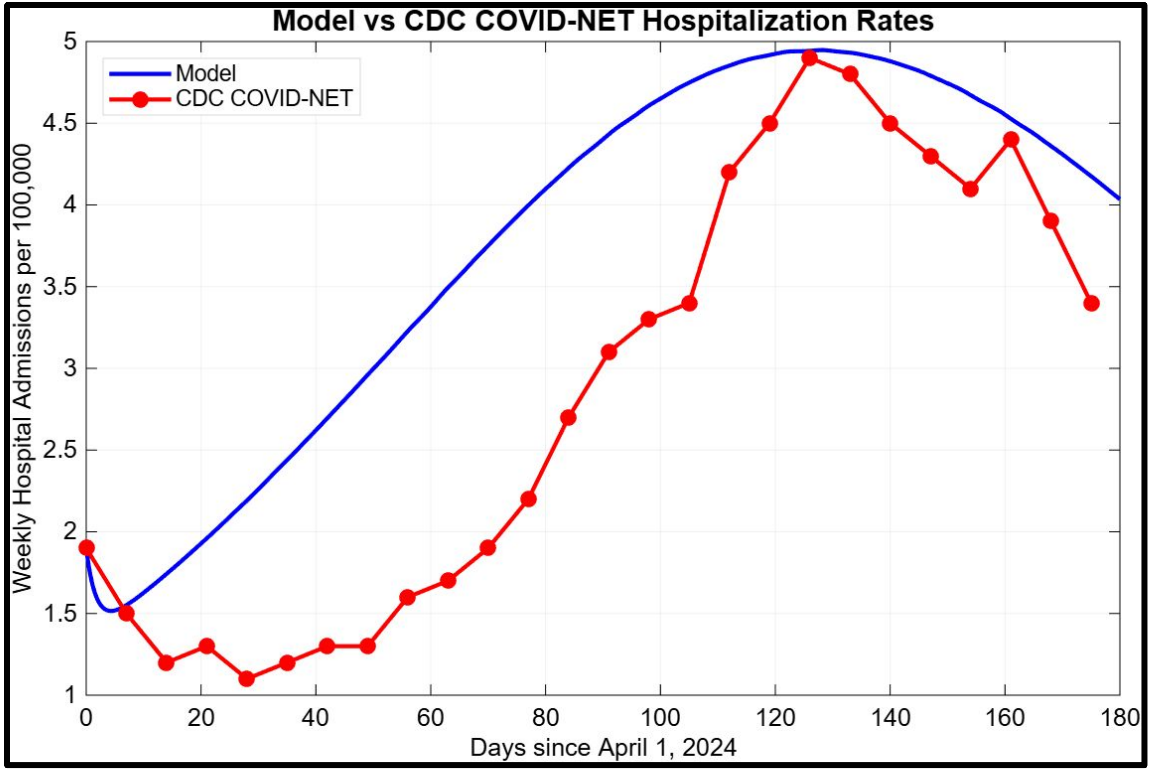
Model Vs Real World Data

Data Source
CDC COVID-NET
Weekly Hospital Admission Rates

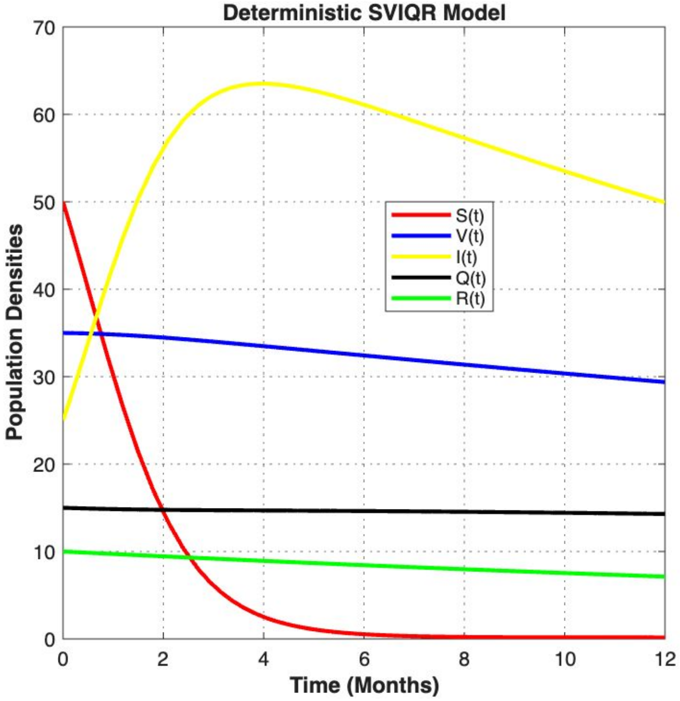
Study Period
April 2024 – September 2024

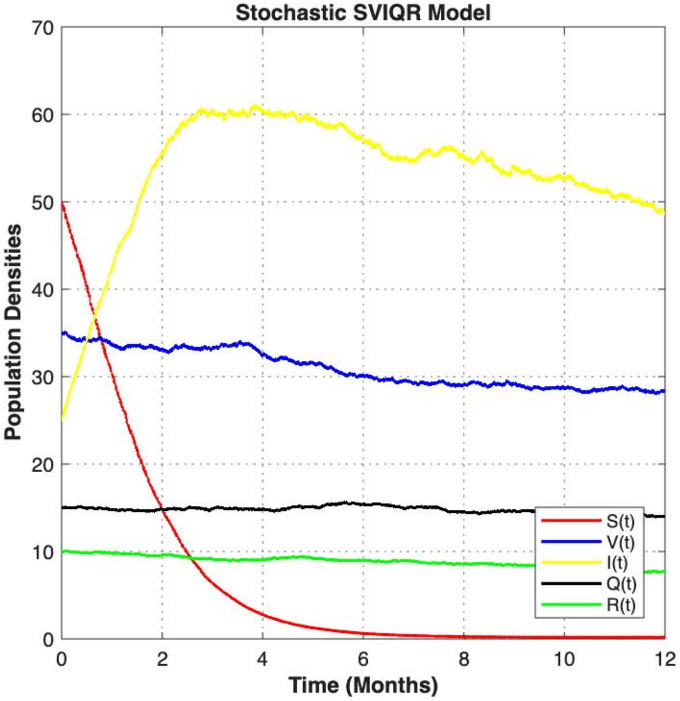
Model Performance
RMSE = 1.08

Key Finding
- Captures the **overall hospitalization trend**
- Peak timing closely matches CDC observations



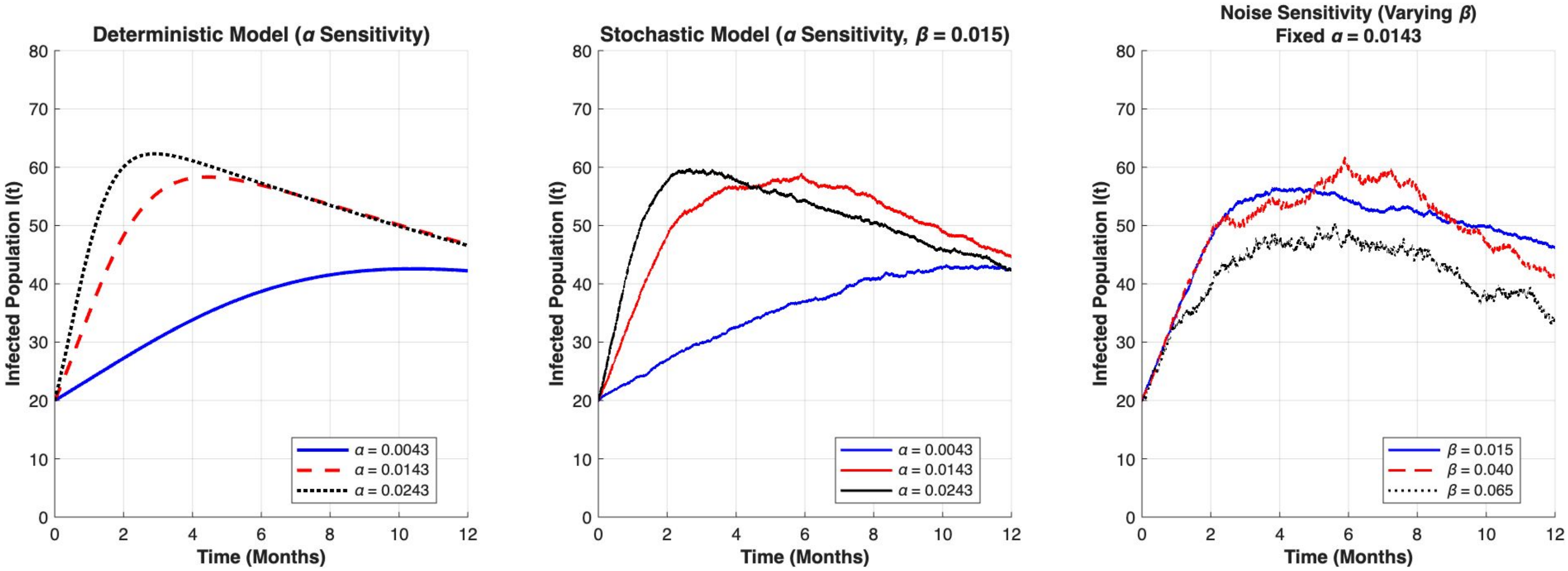
Deterministic & Stochastic SVIQR Models





Parameters Tuning: Deterministic vs. Stochastic models

Transmission Rate (α): Controls the rate at which individuals move from **Susceptible (S)** to **Infected (I)**



Models vs. Real World Data

Data Source:
Public Health Agency of Canada (PHAC) COVID-19 Dataset (.csv)

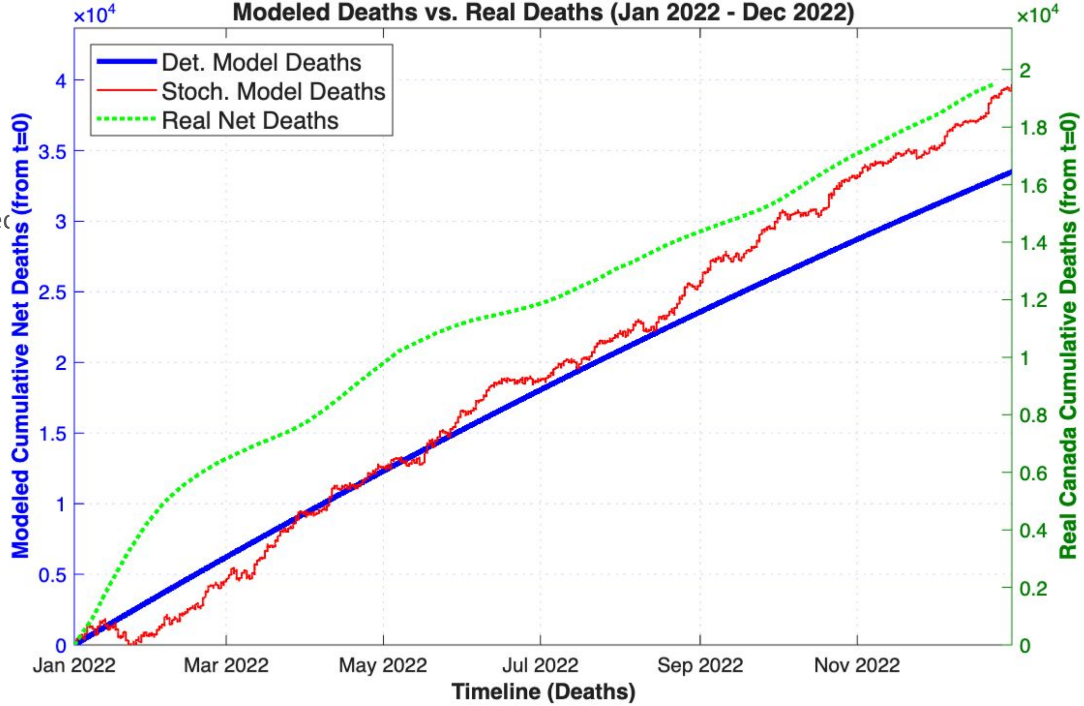
Key Variables:
Weekly deaths (numdeaths_last7) over time (Jan 1, 2022 – Dec 31, 2022); Weekly Infected Cases (numtotal_last7) over time (Sep 1 2020 - Aug 30 2021)

Model Alignment:
Evaluated over a 12-month simulation window

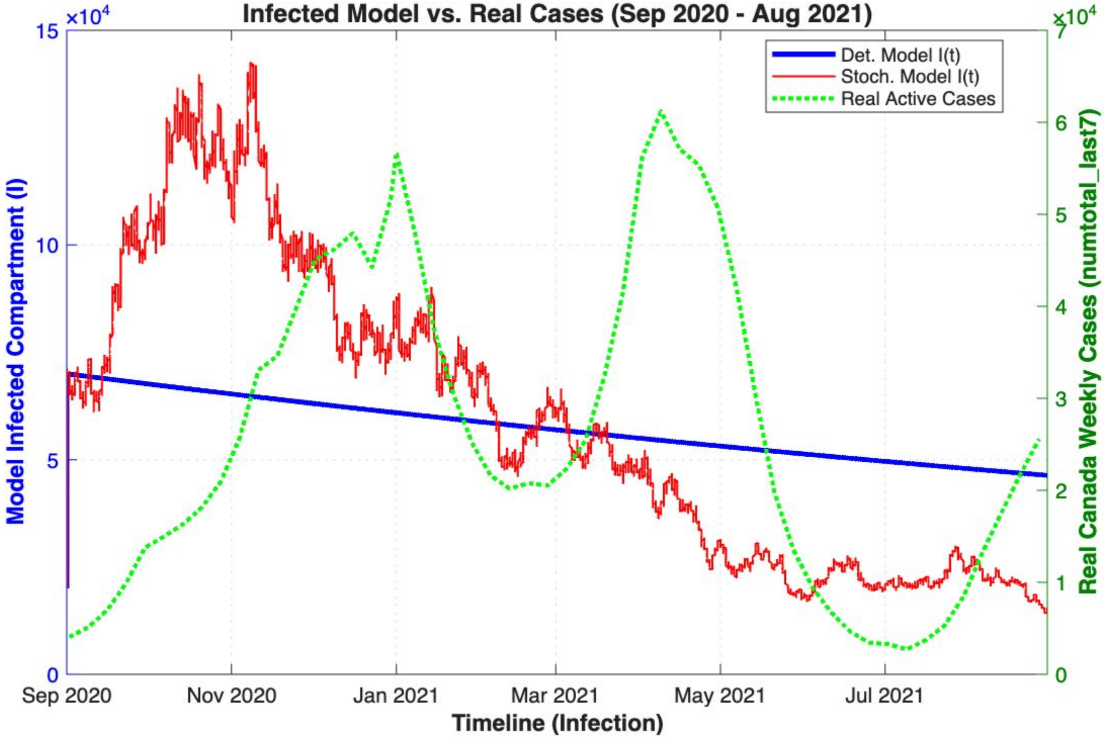
Cumulative Net Deaths Formula:

$$D(t) = N_0 - \sum Y(t)$$

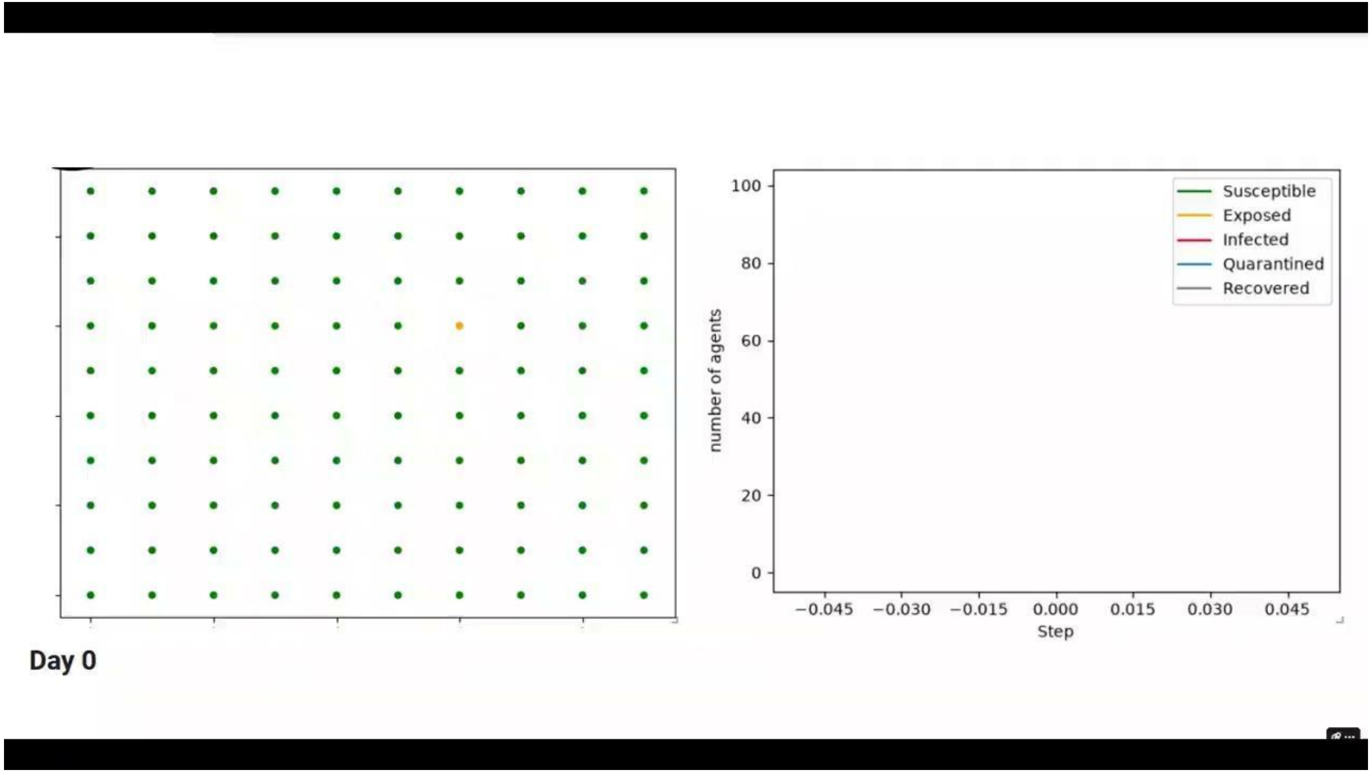
Where N0 is the initial population and $\sum Y(t)$ *is the total living population.*



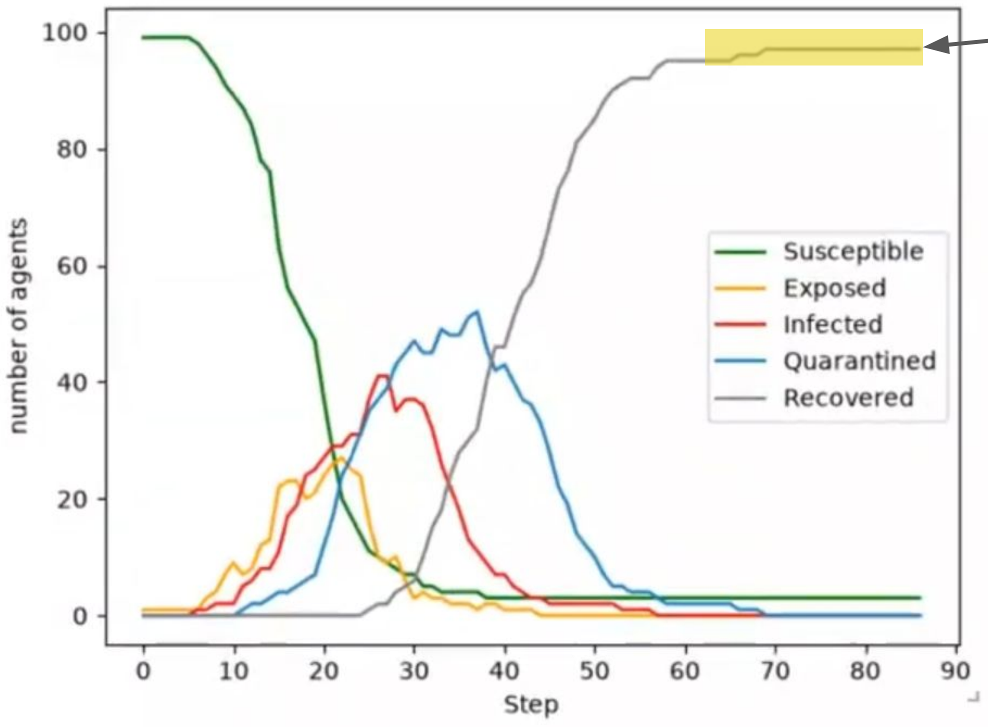
Models vs. Real World Data



Sample ABM simulation



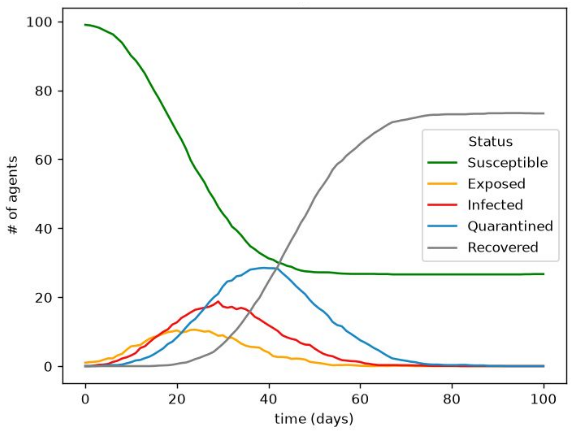
Observations



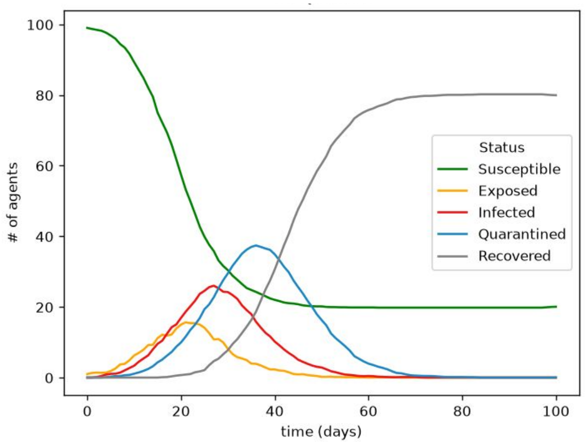
Herd immunity

Effects of compliancy

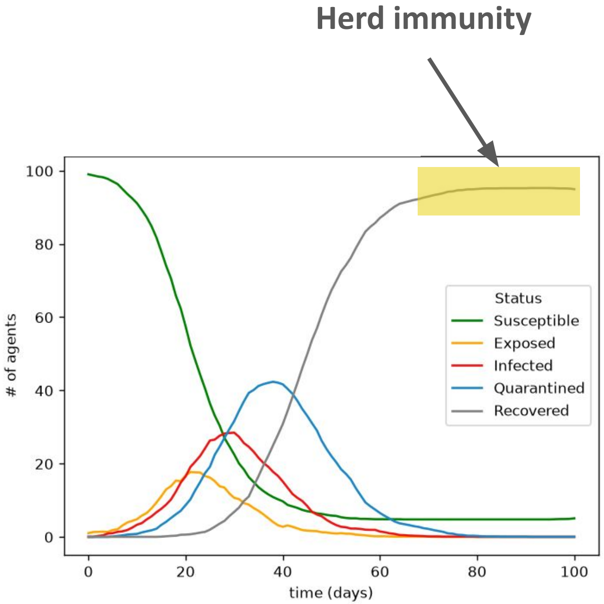
*the graphed results are the mean of 20 simulation runs



95% compliancy



75% compliancy



50% compliancy

Conclusion

Strengths

- Captures the natural variance in real-world data
- Considers the effects of preventive measures & healthcare systems on COVID

Limitations

- Linear ODE Constraints
- Coupled system
- Absence of Age variable
- Small-Population Constraints

Future work

- Introduction of health-based **variables** (Age, seasonal, etc…)
- **Combine** the stochastic and the hospitalization compartments
- **Comparison** with agent base model

Thank you!

Questions?