

12-Month ASKEM Evaluation Scenarios

USE CASE: EPIDEMIOLOGICAL MODELING

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These evaluation scenarios align with the July ensemble challenge, which aims to capture the complexity and nuances around the evolutionary nature of the pandemic, by focusing on various key stages of the pandemic, where there are different dynamics, contexts, and policies in place. The scenarios here ask you to do specific analyses at these time points.

For problems asking you to leverage data and information from external sources (publications, reports), you can use any or all of the links provided, as well as additional sources that you think are important. To inform forecasting, you can decide whether to make a deterministic forecast (by combining information from multiple sources to create point values for parameters), or probabilistic forecast (by using information from multiple sources to create distributions over parameters).

For search and discovery questions that include a time limit, if you aren't able to find meaningful and relevant sources within the indicated time, please reach out to MITRE, who will provide sources, in order to allow work on the scenarios to move forward

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Evaluation Scenario 1: Forecasting With NPIs

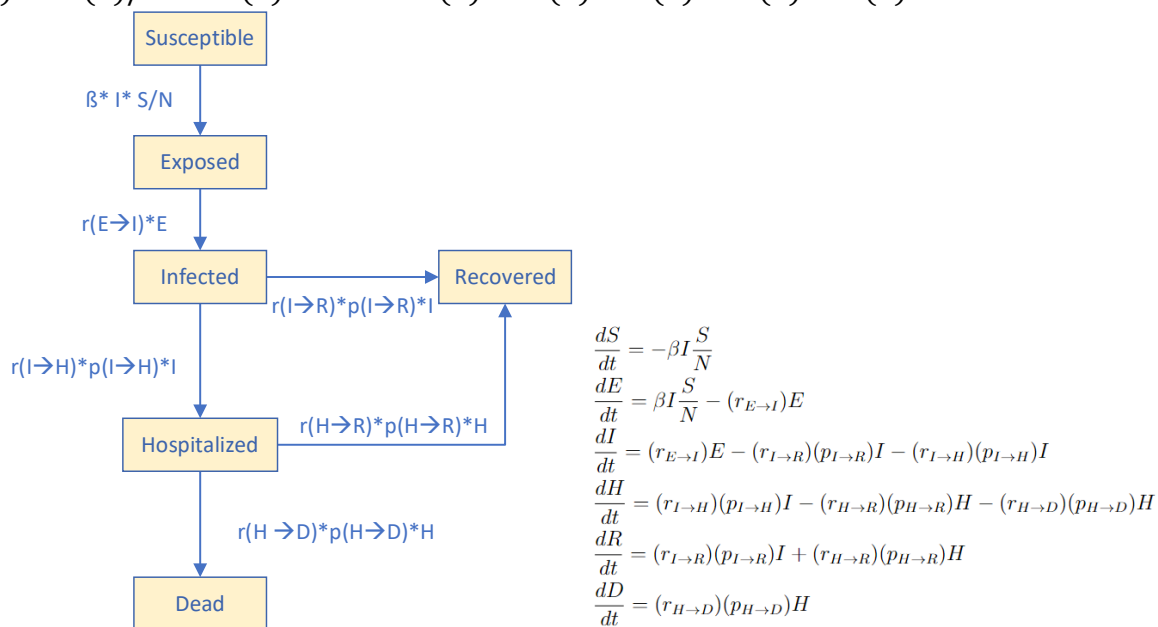
Background: In April 2020, COVID-19 has spread from small clusters of imported cases to more widespread community transmission. Preventive measures are limited to non-pharmaceutical interventions such as social distancing, isolation of infected individuals, and other forms of source control such as masking. We are interested in determining how masking efficacy and compliance can help reduce cases, hospitalizations, and deaths in New York.

Timepoint (Mapping to Forecasting Challenge Timepoint 1): April 3rd, 2020

Location: New York State

Model: Begin with the following SEIRHD model structure and set of differential equations (a version of this may already exist in the workbench; if not, create it). The general form/structure of the model is below. Also see accompanying code.

Note: $p(I \rightarrow R)$ in the diagram on the left is $p_{I \rightarrow R}$ in the equations on the right, and represents the probability of moving between the indicated states. $r(state1 \rightarrow state2)$ represent rates for how long processes take (i.e. 1/average time to move between states, e.g. 1/ incubation period, etc.). For parameter values for the base model (prior to modification tasks in the scenario question), use the following values: $\beta = 0.4$ new infections per infected person/day; $r(I \rightarrow R) = 0.07/\text{day}$; $r(I \rightarrow H) = 0.1/\text{day}$; $r(E \rightarrow I) = 0.2/\text{day}$; $r(H \rightarrow R) = 0.1/\text{day}$; $r(H \rightarrow D) = 0.1/\text{day}$; $p(I \rightarrow R) = 0.8$; $p(I \rightarrow H) = 0.2$; $p(H \rightarrow R) = 0.88$; $p(H \rightarrow D) = 0.12$. Use $N = 19.34$ million (approximate population size for NY state in 2020). For initial conditions $I(0)$ and $D(0)$, please pull values from the [gold standard cases and deaths data from the Covid-19 ForecastHub](#). For $H(0)$ use HHS hospitalization data from <https://healthdata.gov/Hospital/COVID-19-Reported-Patient-Impact-and-Hospital-Capa/g62h-syeh>. Let $R(0) = \text{cumulative infections} - \text{cumulative deaths}$, as of April 3rd, 2020. Let $E(0) = I(0)/4$. Let $S(0) = N - E(0) - I(0) - R(0) - H(0) - D(0)$.



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Data: For comparison against historical data or initializing simulations, use [gold standard data from the Covid-19 ForecastHub](#)

Questions: For the questions below, you will be asked to implement various policy interventions on April 15th, 2020. Forecasts should begin on April 3rd, 2020.

1) Masking Forecasts: For this question, assume that a masking policy will go into place on April 15th, 2020

a) Starting from April 3rd, 2020, forecast the next four weeks of the pandemic (for cases, hospitalizations, and deaths) assuming the following constant levels of masking compliance: 40%, 60%, and 80%. Assume that any person who complies with the masking policy is wearing a surgical mask. How does compliance affect forecasted cases, hospitalizations, and deaths?

i) *(TA1 Search and Discovery Workflow, 1 Hr. Time Limit)* Find estimates on the efficacy of surgical masks in preventing onward transmission of SARS-CoV-2 (preferred) or comparable viral respiratory pathogens (e.g., MERS-CoV, SARS), including any information about uncertainty in these estimates. The term *surgical mask* here refers to the commonly available, disposable procedure mask, not an N95-type respirator. Find 3 credible documents that provide estimates and use your judgment to determine what value (in the deterministic case) or distribution (in the probabilistic case) to use in your forecasts in 1.a.iii.

ii) *(TA2 Model Modification Workflow)* Begin with an SEIRHD model with parameter settings as described in the scenario description. Modify the model to include the ability to implement a masking policy intervention with different compliance levels. Implement this in the following three ways:

(1) Introduce a modification term to β as described in Srivastav et. al. (DOI: 10.3934/mbe.2021010): $(1 - \epsilon_m c_m)$, where c_m is the fraction of the population that wear face masks correctly and consistently (i.e. comply with masking policies), and ϵ_m is the efficacy of the masks themselves.

(2) Adjust the transmission rate following an intervention period and create a time-varying β function, as shown in <https://doi.org/10.3390/ijerph18179027>

(3) Add compartments and transitions to represent mask wearing/non-mask wearing populations. See examples for several similar options of representing this addition; you may implement the update in a way that represents one or a combination of these approaches, or has an otherwise analogous effect:

<https://doi.org/10.1098/rspa.2020.0376>,

<https://doi.org/10.1016/j.idm.2020.04.001>,

<https://doi.org/10.1016/j.chaos.2020.110599>,

<https://doi.org/10.1177/0272989X211019029>

iii) *(TA3 Simulation Workflow)* For each of the mask model modifications in 1.a.ii, create forecasts to show how changes in compliance affect cases, hospitalizations, and deaths.

- b) Repeat question 1a), but use masking compliance rates estimated from the literature or other relevant sources.
- i) *(TA1 Search and Discovery Workflow, 1 Hr. Time Limit)* Find estimates on masking compliance rates from March or April, 2020. It is acceptable if the studies are published after this time period, and if the period of analysis is later in 2020; the goal is to find published examples of compliance rates from roughly the early/mid 2020 period.
 - ii) *(TA3 Simulation Workflow)* Repeat 1.a.iii using these masking compliance rates.
- c) Assume that masking compliance is 100%, but only 50% of individuals have access to surgical masks. The other 50% are using simple cloth masks.
- i) *(TA1 Search and Discovery Workflow, 1 Hr. Time Limit)* Find estimates on the efficacy of simple cloth masks in preventing transmission of SARS-CoV-2, including any information about uncertainty.
 - ii) *(TA2 Model Modification Workflow)* Make any required modifications to the models you've been working with in 1.a.ii, to include combinations of different types of masks.
 - iii) *(TA3 Simulation Workflow)* Create forecasts to show how a mix of different types of masks affects cases, hospitalizations, and deaths.
 - iv) *(TA3 Simulation Workflow)* Create a forecast showing the effect of providing surgical masks to *all* residents, with a 100% compliance rate. Assume that mask effectiveness does not decrease over time. Compare the forecasts for cases, hospitalizations, and deaths with the forecast from 1.a.iii and 1.b.ii.

	Problem 1a	Problem 1b	Problem 1c
Inputs	<ul style="list-style-type: none"> Model: SEIRHD as defined in scenario description Parameters: As defined in problem 	<ul style="list-style-type: none"> Model: 3 modified SEIRHD models with masking implemented in different ways, from Problem 1a Parameters: As defined in problem 	<ul style="list-style-type: none"> Model: 3 modified SEIRHD models with masking implemented in different ways, from Problem 1a Parameters: As defined in problem
Tasks	<ul style="list-style-type: none"> Find estimates on surgical mask efficacy Modify model to include mask interventions, in 3 different ways Forecasting with different mask compliance levels 	<ul style="list-style-type: none"> Find estimates on masking compliance Forecasting with different mask compliance levels found in the literature 	<ul style="list-style-type: none"> Find estimates on cloth mask efficacy Modify models to include different types of masks Forecasting with different mixes of mask types
Outputs	<ul style="list-style-type: none"> 4-week forecasts for cases, hospitalizations, and deaths, starting April 3rd, 2020 Modified/extended SEIRHD model 	4-week forecasts for cases, hospitalizations, and deaths, starting April 3 rd , 2020	<ul style="list-style-type: none"> 4-week forecasts for cases, hospitalizations, and deaths, starting April 3rd, 2020 Modified/extended SEIRHD model

- 2) **Social Distancing Forecasts.** Instead of providing masks for all residents, the governor is interested in enforcing a social distancing policy to reduce contact between individuals. As before, begin with an SEIRHD model as described in the scenario description. For this question, assume that a social distancing policy will go into place on April 15th, 2020. Starting from April 3rd, 2020, forecast the next four weeks of the pandemic (for cases, hospitalizations, and deaths)
- a) Assume that the governor puts in place a social distancing policy that reduces the contact rate between individuals to 50% of its normal rate pre-pandemic. Assume that there is a uniform contact rate across the population (i.e., there is no spatial heterogeneity or heterogeneity between demographic subgroups in the population).
 - i) *(TA1 Search and Discovery Workflow, 1 Hr. Time Limit)* Find estimates on contact rates pre-pandemic and during the pandemic.
 - ii) *(TA3 Simulation Workflow)* Assuming that there is only a social distancing policy (and no masking policy) in place, create forecasts for cases, hospitalizations, and deaths beginning on April 3rd, 2020. Assume the social distancing policy goes into effect on April 15th, 2020, and implement it by reducing the average contact rate between individuals to half its normal pre-pandemic level.
 - b) In practice, social distancing may not reduce the contact rate by half. Use realistic impact estimates from the literature.
 - i) *(TA1 Search and Discovery Workflow, 1 Hr. Time Limit)* Find information on how social distancing reduces contact rates, including any uncertainty information where available.
 - ii) *(TA3 Simulation Workflow)* Create forecasts for cases, hospitalizations, and deaths, using effects of social distancing on contact rate pulled from the literature.
 - c) Stratify the SEIRHD model to align with the population of New York state and 18 age groups.
 - i) Assume that social distancing reduces the contact rates within and between each stratum, by 50%.
 - (1) *(TA1 Data Workflow)* Get New York State contact matrices from this repository (<https://github.com/mobs-lab/mixing-patterns/tree/main>) and this paper (<https://www.nature.com/articles/s41467-020-20544-y>). In particular, extract 'United_States_subnational_New_York_M_overall_contact_matrix_18.csv', which is stratified by the 18 age groups specified below. The GitHub page states, "the overall contact matrix element M_{ij} can then be thought of as representing the per capita number of contacts an individual of age i has with individuals of age j ." Normalize this contact matrix by row, for use in setting values of new interaction parameters introduced by the stratification process.
 - (2) *(TA2 Model Stratification Workflow)* As before, begin with an SEIRHD model as described in the scenario description. Stratify it by 18 age groups (0-4, 5-9, 10-14, 15-19, 20-24, ..., 80-84, 85+). For simplification purposes, before performing the stratification, you may remove the Exposed compartment. The final result for this question will be a stratified SIRHD model. Use the following data for population

estimates / initial conditions:

https://www.health.ny.gov/statistics/vital_statistics/2016/table01.htm

Update parameters and probabilities introduced from stratification, with reasonable assumptions, from (for example) the following resources:

<https://www.cdc.gov/coronavirus/2019-ncov/hcp/planning-scenarios.html>

https://docs.buckymodel.com/en/latest/input_output.html

<https://doi.org/10.3389/fpubh.2020.598547>

<https://doi.org/10.3201/eid2611.201074>

- (3) *(TA3 Simulation Workflow)* Assume that social distancing reduces the contact rate within and between each stratum, by 50%. Forecast cases, hospitalizations, and deaths under these conditions, and compare with 2.a.ii and 2.b.ii. *Note:* This is how the 18x18 contact matrices are defined (it is not specified in the paper or the supplemental information.)

```
if num_agebrackets == 18:
    for i in range(16):
        brackets.append(np.arange(5 * i, 5 * (i + 1)))
    brackets.append(np.arange(80, 84))
    brackets.append(np.arange(84, 101))
```

If it is easier, you can use the 85x85 contact matrices, where the last row represents ages 84-101.

- ii) **Bonus:** In practice, a social distancing policy may affect different age groups differently.
- (1) *(TA1 Search and Discovery Workflow, 1 Hr. Time Limit)* Search for information on how social distancing policies can affect different age groups differently.
- (2) *(Optional TA2 Model Modification Workflow)* Make any necessary modifications to take into account the age strata-specific effect of social distancing
- (3) *(TA3 Simulation Workflow)* Create forecasts for cases, hospitalizations, and deaths. How do outcomes differ between age groups?

	Problem 2a	Problem 2b	Problem 2c
Inputs	<ul style="list-style-type: none">Model: SEIRHD as defined in scenario description	<ul style="list-style-type: none">Model: SEIRHD as defined in scenario description	<ul style="list-style-type: none">Model: SEIRHD as defined in scenario description
Tasks	<ul style="list-style-type: none">Find information on contact rates pre-pandemic and during the pandemicCreate 4-week forecasts with social distancing policy	<ul style="list-style-type: none">Find information on how social distancing reduces contact rateCreate 4-week forecasts with social distancing policy	<ul style="list-style-type: none">Remove E compartment and stratify by 18 age groupsFind contact matrix data and align with stratified modelCreate 4-week forecasts for individual age groups, with social distancing policy
Outputs	<ul style="list-style-type: none">4-week forecasts for cases,	<ul style="list-style-type: none">4-week forecasts for cases, hospitalizations, and	<ul style="list-style-type: none">Age-stratified SIRHD model

	hospitalizations, and deaths, starting April 3 rd , 2020	deaths, starting April 3 rd , 2020	<ul style="list-style-type: none"> 4 week forecasts for cases, hospitalizations, and deaths, starting April 3rd, 2020
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3) *(TA3 Simulation Workflows)* The governor is interested in determining which combination of the above interventions (increasing masking compliance; increasing masking efficacy; and social distancing) provides the biggest reduction in cases, hospitalizations, and deaths. To do that, create the following forecasts, and compare them in terms of cases, hospitalizations, and deaths.

- Assume 40% of the population is wearing a surgical mask, 40% of the population is wearing a cloth mask, and 20% of the population is wearing no mask. Simultaneously, assume that social distancing reduces the contact rate by 50% uniformly across all ages.
- Assume 20% of the population is wearing a surgical mask, 60% is wearing a cloth mask, and 20% is wearing no mask. Simultaneously, assume that social distancing reduces the contact rate by 75% uniformly across all ages.
- Assume 80% of the population is wearing a surgical mask, 20% is wearing no mask, but due to people feeling more comfortable with wearing masks, social distancing reduces the contact rate only by 25% uniformly across all ages.

	Problem 3
Inputs	Model from Problem 1c (any non-stratified model which includes implementations for different kinds of masks and social distancing)
Task	Create forecasts of different combinations of masking and social distancing
Outputs	4-week forecasts for cases, hospitalizations, and deaths, starting April 3 rd , 2020, for each of the 3 masking/social distancing combinations

Evaluation Scenario 2: Forecasting With Vaccines

Timepoint (Mapping to Forecasting Challenge Timepoint 2): July 15th, 2021

Location: New York state

Background: The Delta variant is beginning to spread around the country, including in New York state. Vaccine campaigns have been underway in select groups since the early part of 2021, but the distribution process has a long tail and is still ongoing.

- Recall that children 11 and under were unable to be vaccinated until November 2nd, 2021. For this scenario, assume that children under 10 (instead of 11) were unable to be vaccinated. (<https://www.kff.org/coronavirus-covid-19/issue-brief/an-update-on-vaccine-roll-out-for-5-11-year-olds-in-the-u-s/#:~:text=Introduction,first%20countries%20to%20do%20so>).
- Data sources:
 - For comparison against historical data or initializing simulations, use [gold standard data from the Covid-19 ForecastHub](#)
 - [https://en.wikipedia.org/wiki/COVID-19_pandemic_in_New_York_\(state\)#Government_response](https://en.wikipedia.org/wiki/COVID-19_pandemic_in_New_York_(state)#Government_response)
 - <https://www.governor.ny.gov/news/governor-cuomo-announces-covid-19-restrictions-lifted-70-adult-new-yorkers-have-received-first>

Model: Update the model from Scenario 1 to have multiple vaccination compartments. For parameter values for the base model (prior to modification tasks in the scenario question), use the following values: $\beta = 0.8$ new infections per infected person/day; $r(I \rightarrow R) = 0.07/\text{day}$; $r(I \rightarrow H) = 0.1/\text{day}$; $r(E \rightarrow I) = 0.2/\text{day}$; $r(H \rightarrow R) = 0.1/\text{day}$; $r(H \rightarrow D) = 0.1/\text{day}$; $p(I \rightarrow R) = 0.9$; $p(I \rightarrow H) = 0.1$; $p(H \rightarrow R) = 0.85$; $p(H \rightarrow D) = 0.15$. Use $N = 19.34$ million (approximate population size for NY state in 2020). For initial conditions $I(0)$ and $D(0)$, please pull values from the [gold standard cases and deaths data from the Covid-19 ForecastHub](#). For $H(0)$ use HHS hospitalization data from <https://healthdata.gov/Hospital/COVID-19-Reported-Patient-Impact-and-Hospital-Capa/g62h-syeh>. Let $R(0) = \text{cumulative infections} - \text{cumulative deaths}$, as of July 15th, 2021. Let $E(0) = I(0)/4$. Let $S(0) = N - E(0) - I(0) - R(0) - H(0) - D(0)$.

Questions: For the questions below, forecasts should be for New York State, and proceed for four weeks unless otherwise specified.

- You are interested in making a forecast for cases, hospitalizations, and deaths, over the next four weeks, incorporating information on vaccine uptake. Use the following data on vaccine efficacy for Moderna, Pfizer, and J&J vaccines, including any uncertainty information that is provided.
 - (No task in part a) Use uptake rates of the vaccines in New York state, and information on number of people vaccinated, as of July 15th, 2021. You can assume that these uptake rates remain constant during the four-week window.

- (1) Science paper on decline of vaccine effectiveness over time.
<https://www.science.org/doi/10.1126/science.abm0620>
- (2) CDC Vaccine Efficacy Data
<https://covid.cdc.gov/covid-data-tracker/#vaccine-effectiveness>
- (3) Vaccination data sources:
<https://coronavirus.health.ny.gov/vaccination-progress-date>
<https://health.data.ny.gov/Health/New-York-State-Statewide-COVID-19-Vaccination-Data/duk7-xrni>
<https://data.cdc.gov/Vaccinations/COVID-19-Vaccinations-in-the-United-States-Jurisdiction/unsk-b7fc>
- b) *(TA2 Model Modification Workflow)* Begin with the SEIRHD model from Scenario 1, and extend the model to incorporate the inclusion of vaccines of different efficacies, and with multiple doses, in a similar way to [SV2\(AIR\)3](#). Also include masking effects in the model by incorporating a beta modification term (as in DOI: 10.3934/mbe.2021010), in particular for those who are unvaccinated.
- c) *(TA3 Simulation Workflow)* Per the June 24, 2021 order, assume that general masking and social distancing are no longer in place in NY state, but that all unvaccinated people still need to wear masks
[https://ballotpedia.org/Documenting_New_York%27s_path_to_recovery_from_the_coronavirus_\(COVID-19\)_pandemic,_2020-2021](https://ballotpedia.org/Documenting_New_York%27s_path_to_recovery_from_the_coronavirus_(COVID-19)_pandemic,_2020-2021)). Assume 50% of unvaccinated people comply and wear masks. For this scenario, assume all masks are surgical masks. Let β_{uv} be the infection rate per day per infected person, between two types of populations u and v , where u is the unvaccinated population and v is the vaccinated population. Assume $\beta_{uu} = \beta$ (from the scenario definition); $\beta_{uv} = \beta_{vu} = (1 - vaccine_efficacy) * \beta_{uu}$; $\beta_{vv} = (1 - vaccine_efficacy)^2 \beta_{uu}^2$. Create forecasts of cases, hospitalizations, and deaths using the updated model in 1b. Forecasts should begin on July 15th, 2021, and proceed for four weeks.

	Problem 1b	Problem 1c
Inputs	SEIRHD model from the end of Scenario 1	Updated model from 1b
Task	<ul style="list-style-type: none"> Modify model to include vaccination compartments for different vaccines (and different efficacies) Modify the model to include masking with a beta modification term 	Create forecasts of specified outputs
Outputs	Modified model which includes vaccination compartments and masking	4-week forecasts of cases, hospitalizations, and deaths

- 2) In August 2021, New York State is hoping to reopen schools for the fall. Recall that children 11 and under were unable to be vaccinated until November 2nd, 2021. For this scenario, assume that children under 10 (instead of 11) were unable to be vaccinated.
<https://www.kff.org/coronavirus-covid-19/issue-brief/an-update-on-vaccine-roll-out-for-5-11-year-olds-in-the-u-s/#:~:text=Introduction,first%20countries%20to%20do%20so>).

Assuming the continued uptake of vaccines and the conditions found in Question 1, create a forecast of cases, hospitalizations, and deaths for Fall 2021. The forecast should begin on September 1, 2021, and continue for the entire month of September.

- a) *(TA2 Model Modification Workflow)* At the start of the 2021-2022 school year, NY state [mandated all unvaccinated people to wear masks, and asked all eligible adults to be vaccinated.](#) Begin with the final model from Problem 1 and retain all masking settings from that model. To separate out school-aged people from those who aren't school-aged, stratify the model into three age groups: those aged 0-9, corresponding to those in school or daycare who cannot be vaccinated; those aged 10-19, corresponding to those in school settings who can be vaccinated; and those aged 20 and above, corresponding to those outside of the school setting. Use the normalized contact value matrices supplied in the tables below to set the values for interaction parameters introduced by stratification. For school openings, assume that all β values for school-aged kids are increased by 1.5x. Update parameters and probabilities introduced from stratification, with reasonable assumptions, from (for example) the following resources:
<https://www.cdc.gov/coronavirus/2019-ncov/hcp/planning-scenarios.html>;
https://docs.buckymodel.com/en/latest/input_output.html;
<https://doi.org/10.3389/fpubh.2020.598547>; <https://doi.org/10.3201/eid2611.201074>
<https://www.cdc.gov/mmwr/volumes/71/wr/mm7137a4.htm>

Table 1. Number of contacts per day (in millions) for all people in the State of New York by age strata

Age Strata	0-9	10-19	20+
0-9	14.17	4.8	14.2
10-19	4.8	21.5	17.89
20+	14.2	17.89	147.2

Table 2. Table 1 normalized by its row sums

Age Strata	0-9	10-19	20+
0-9	0.43	0.14	0.43
10-19	0.11	0.49	0.40
20+	0.08	0.10	0.82

- b) *(TA3 Simulation Workflow)* Using the age-stratified model from 2a, create a forecast for hospitalizations, infections, and deaths starting on September 1, 2021, and continue for the entire month of September. To set initial conditions, use population and vaccination data from https://www.health.ny.gov/statistics/vital_statistics/2016/table01.htm, <https://health.data.ny.gov/Health/New-York-State-Statewide-COVID-19-Vaccination-Data/duk7-xrni>, and <https://data.cdc.gov/Vaccinations/COVID-19-Vaccinations-in-the-United-States-Jurisd/unsk-b7fc>. Compare outcomes for the three different age groups.

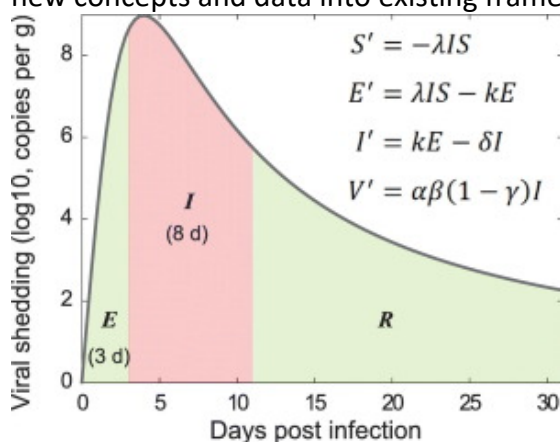
	Problem 2a	Problem 2b
Inputs	<ul style="list-style-type: none"> Supplied contact matrix Model from Problem 1 	Model from part 2a
Task	<ul style="list-style-type: none"> Stratify the model by age group Modify the model (by scaling β or other transformation) to adjust for the changes in contact rates between age groups, due to school reopening 	Create a forecast using the model for the month of September
Outputs	Updated model with three age strata and changed β based on the contact rates	Forecast for hospitalizations, infections, and deaths for September

- 3) Assume now that all children could be vaccinated as of August 1, 2021, in time for schools to reopen in the fall. This was not actually the case, but we want to understand the impact of children being vaccinated before schools reopened.
- a) *(TA1 Search and Discovery)* Find information on vaccine effectiveness for children under the age of 11. The effectiveness numbers may have been published after September 1, 2021 – this is completely acceptable.
- b) *(TA3 Simulation Workflow)* Use the final age-stratified model with vaccination compartments, from Problem 2. Starting on September 1st, 2021, create a forecast for the entire month of September, assuming all children can be vaccinated. Assume that children under the age of 10 started to be vaccinated on August 1st, 2021, at a rate of 0.5% (of this age group) being vaccinated per day.
- With children being vaccinated, create forecasts where all school attendees (including those vaccinated) still need to be masked.
 - Create forecasts where those attending school who are vaccinated do not need to wear masks, but everyone who is not vaccinated is wearing a mask.
 - Create forecasts where no one needs to wear a mask, regardless of vaccination status.

	Problem 3a	Problem 3b
Inputs		Final model from Problem 2
Task	Find information on vaccine effectiveness in children for the different vaccines	Create forecasts under the various combinations of mask/vaccination
Outputs	Vaccine effectiveness information ingested into workbench	Forecasts of cases, hospitalizations, and deaths for all specified combinations of masks/vaccinations

Evaluation Scenario 3: Modeling Approaches to Address Underreporting with Wastewater

Background: Official COVID-19 case counts have dramatically underestimated the true number of infections since the initial documented cases in the United States in early 2020, due to supply constraints on testing and variations in test-seeking behavior. The underreporting of COVID-19 cases due to these factors also varies over time, meaning that simply scaling the observed cases to estimate actual infections would yield inaccurate results. Wastewater-based surveillance is a promising tool to estimate the actual, rather than recorded cases in a population, because the concentration of SARS-CoV-2 in the water is not affected by testing supply or test-seeking behavior. This approach is emerging, and researchers have had mixed success in predicting cases based on wastewater signals. Integrating wastewater-based surveillance into phenomenological models is an area of active inquiry but is challenging due to the need to map new concepts and data into existing frameworks (e.g., SIR).



Timepoint: October 2020 - January 2021

Location: Greater Boston area; optional extension to NYC context

Model: SEIR-V model (Phan et al.) <https://doi.org/10.1016/j.scitotenv.2022.159326>

Data: Derived from supplementary materials in paper

Questions:

- 1) You want to utilize this SEIR-V model to estimate the true number of underlying infections (as opposed to officially reported cases) based on wastewater data.
 - a) *(TA1 Model Extraction Workflow, Data Workflow)* Extract/replicate the system of equations for the SEIR-V model. Extract the appropriate data columns (cRNA2 and F2, which represent the viral load in wastewater and the flow rate, respectively) from the paper's supplemental materials.
 - b) *(TA2 Domain Knowledge Grounding; ASKEM Workbench Only)* We want to ensure that terms from the model are grounded appropriately given that it involves several nontraditional concepts. For example, typically, "V" in the compartmental modeling framework represents a vaccination compartment. This model retains many

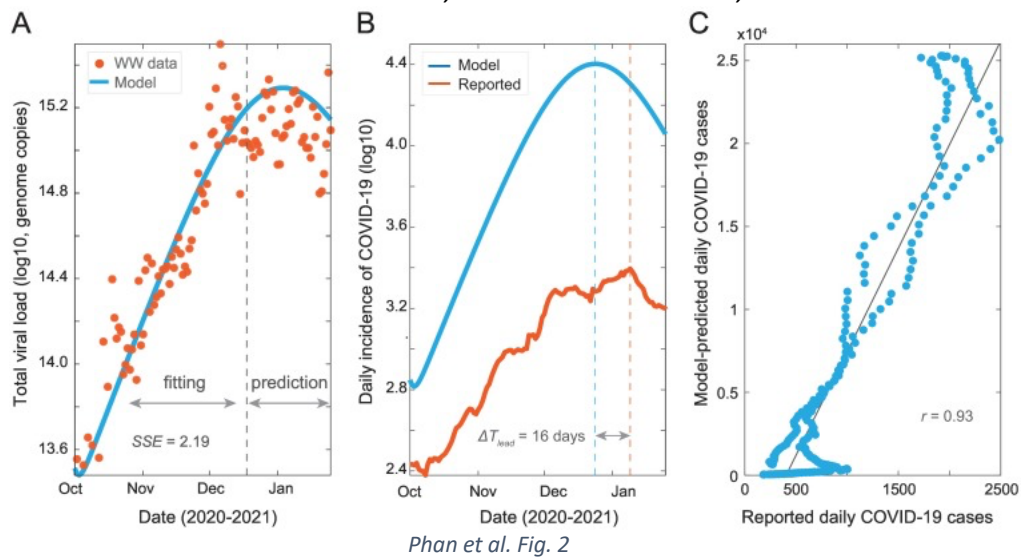
Distribution Statement A. Approved for public release: distribution is unlimited

MITRE Public Release Case Number 24-2089

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concepts of the traditional compartmental modeling framework, but “V” here represents a novel concept of cumulative viral load in wastewater. Demonstrate that state variables and parameters are grounded appropriately to their descriptions in the paper, including through manual adjustment in the workbench as necessary.

- c) *(TA3 Simulation Workflow / Unit Test)* Demonstrate that the extracted model from 1a maintains fidelity to the original model by replicating the fitting exercise in the publication’s Section 3.2 (visual output available in Figure 2A of the paper), using wastewater viral concentration data (available in the supplementary materials). You may simplify wherever necessary, such as by fixing the value of β to the fecal viral shedding rate implemented in the paper (4.49×10^7 viral RNA/g). Use assumptions from Table 1 in the paper to inform parameter values that are derived from literature (i.e., “exposed duration”, “infectious duration”) and fit λ , α , and $E(0)$ to the wastewater data from *October 02, 2020 to December 18, 2020*.



- d) *(TA3 Simulation Workflow / Unit Test)* Do a forecast from December 18, 2020 to January 25, 2021, and compare with the forecast in Fig. 2A for this prediction period.
- e) *(TA3 Simulation Workflow)* For the prediction period from December 18, 2020 to January 25, 2021, incorporate uncertainty into the forecast process by exploring reasonable parameter ranges where point estimate assumptions are made in the paper. Create a probabilistic forecast and plot the results.
- f) *(TA3 Optional/Bonus Simulation Workflow)* Incorporate temperature data (from the supplementary materials) into the fitting/prediction, as in Section 3.3 from the paper, to replicate Figure 3A. Demonstrate that the incorporation of temperature data improves the fit.

	Problem 1a	Problem 1b (ASKEM Workbench Only)	Problem 1c-f
Inputs	Paper and supplementary materials (code + data)	Extracted model from 1a	Model from 1b

Task	Extract SEIR-V model, metadata, concepts from paper	Ingest, inspect, and update domain knowledge groundings	Run simulation to include calibration and forecasting
Outputs	SEIR-V system of equations, replicated in form that can be implemented in workbench	Demonstration of groundings (state variables, parameters) mapped correctly to associated concepts from paper	Plots that roughly replicate Figure 2 of the paper

- 2) To reconstruct panel B from Figure 2, the fitted/predicted curve (currently with y-axis of “total viral load”) needs to be transformed into estimated daily incidence of COVID-19.
- (TA3 Simulation Workflow)* Begin with the extracted model from Problem 1. Due to the unique structure of the model, the total viral load can be transformed into estimated true daily incidence in a fairly straightforward manner; this mapping can be done following Equation 9 in Section 2.7. (Performers: generate an observation function to complete this step, if appropriate).
 - (TA3 Simulation Workflow)* Plot the fitted/predicted curve against the actual case data (obtained from the supplementary materials), which provides a time series of the officially reported case data from the entire catchment area of the wastewater treatment plant; this should look similar to panel B from Figure 2, above.
 - (TA1 Optional/Bonus Search and Discovery Task; Limit 1 hr)* Compare the difference between estimated infections and observed case counts to other estimates of underreporting of COVID-19 data from the literature to determine if the results of the above exercise(s) are reasonable.

	Problem 2a	Problem 2b	Problem 2c
Inputs	<ul style="list-style-type: none"> Methods/context from paper Extracted model from Problem 1 	<ul style="list-style-type: none"> Output of Problem 1c-e + transformation in 2a Case data from paper’s supplemental materials 	Output of Problem 2b
Task	Transform virus concentration in wastewater to number of estimated incident infections	Plot estimated incident infections against actual case data	Knowledge extraction from literature
Outputs	Transformation of panel A from Figure 2 to reconstruct panel B from Figure 2	Reproduce Panels B/C from Figure 2 + rough order of magnitude of estimated underreporting	Comparison against differences between curves from 2b simulations

- 3) You want to explicitly represent the officially reported (diagnosed) cases in the model.
- (TA2 Model Modification Workflow)* Begin with the final model from Problem 2, which includes an observation function for estimated infections (incidence case

counts). Modify this model to include diagnosed cases (represented by actual observational case data) explicitly by adding a new compartment into the model.

- b) *(TA3 Simulation Workflow)* Calibrate the modified model from 3a, by fitting the output from the new compartment (“diagnosed” cases) to actual observational case data from *October 02, 2020 to December 18, 2020*, obtained from the supplemental materials (represented by the orange curve from panel B in Figure 2). With the calibrated model, create a forecast that includes both estimated infections (daily incidence case counts) and actual daily incidence ‘diagnosed’ cases, from December 18, 2020 to January 25, 2021, as in Section 3.2 from the publication. Compare the forecasted daily incidence case counts, with actual observational case counts from that period.

	Problem 3a	Problem 3b
Inputs	Output from 2a/b	Model from 3a
Task	Model modification	Fit new compartment to actual case data from paper
Outputs	Modified model that includes both an estimated true infections compartment and a diagnosed/reported compartment	Similar to panel B from Figure 2, but with a new curve that is fitted to the orange “actuals” curve and a forecast of this curve, consistent with the forecasting of estimated true infections

- 4) **Challenge:** Now that you have recreated the SEIR-V model in its original setting, you want to apply it in a new context, in early 2022. Continuing the thread from Scenarios 1 and 2 in this document, assume you are in the shoes of a modeler supporting decision makers in New York throughout the ever-evolving pandemic. You have added complexity to address nonpharmaceutical interventions and vaccination, and now you want to address the challenge of severe underreporting as we enter a new phase of the pandemic with widely available at-home testing kits. You want to use wastewater data to understand how much underreporting may have changed before and after the implementation of at-home testing.

- a) *(TA1 Data Workflow)* The City of New York maintains openly available COVID-19 wastewater monitoring data at <https://data.cityofnewyork.us/Health/SARS-CoV-2-concentrations-measured-in-NYC-Wastewat/f7dc-2q9f/data>. Extract the relevant data columns (viral load, population served); you will also need the flow rate to implement the SEIR-V model. This can be found in Table S1 of the supplemental materials of <https://doi.org/10.1039/D1EW00747E>. Extract this data from the table.
- b) *(TA3 Optional/Bonus Simulation Workflow)* The national at-home testing program (tests via USPS) rolled out in early 2022. This coincided with the Omicron variant peak in January/February 2022. Look at wastewater data for the Staten Island catchment area (the only borough with wastewater facilities that are not shared with other boroughs) and conduct pre/post intervention (i.e. treat the at-home testing program rollout as an intervention) fitting of the SEIR-V model to wastewater data as implemented in Phan et al. for Boston (make assumptions/simplify where necessary, such as in the temperature effect). In other words, estimate the degree of underreporting pre-testing program, and post-testing program rollout. Repeat for all boroughs combined.