Projecting COVID-19 Hospitalizations and Deaths under Scenarios of Vaccination in Jefferson County, Kentucky

Projection Period:
10 February 2021 – 20 May 2021

Draft Preparation Date: March 6, 2021
Authors:

University of Louisville (School of Public Health and Information Sciences):
Seyed M. Karimi, PhD. Seyed.Karimi@Louisville.edu
Hamid Zarei, MS. Hamid.Zarei@louisville.edu
W. Paul McKinney, MD. McKinney@louisville.edu
Bert Little, PhD. Bert.Little@louisville.edu
Natalie DuPre, ScD. Natalie.Dupre@louisville.edu
Riten Mitra, PhD. RitenDranath.Mitra@louisville.edu
Naiya Patel, MPH. Naiya.Patel@louisville.edu

Louisville Metro Department of Public Health & Wellness (LMPHW)
Yu Ting Chen, MPH. YuTing.Chen@louisvilleky.gov
Rebecca Hollenbach, MPH. Rebecca.Hollenbach@louisvilleky.gov
Sarah Moyer, MD. Sarah.Moyer@louisvilleky.gov

Kentucky Cabinet for Health and Family Services (KY CHFS)
Maik H. Schutze, MHS. Maik.Schutze@ky.gov
Ryan LaZur, MS. Ryan.Lazur@ky.gov
Takeaways:

- In February 2021, the total weekly number of doses of COVID-19 vaccines administered in Jefferson County, KY, was approximately 30,000.

- Receiving 30,000 doses of Pfizer and Moderna vaccines (15,000 of each dose) weekly was considered the status quo assumption scenario in this study.

- Scenarios of expanding the vaccination intensity were evaluated in two ways: (1) the county will receive 10,000 additional doses of Pfizer and Moderna vaccines weekly, and (2) doses of the Johnson & Johnson vaccine will be distributed and administered.

- Under each expansion scenario, a decrease in active COVID-19 hospitalizations on specific dates compared to the status quo scenario was projected to be:

<table>
<thead>
<tr>
<th>Date</th>
<th>Status Quo Scenario + 10k Extra Doses of Pfz &amp; Mod (wkly) + the Following Numbers of J &amp; J Vaccines (wkly):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 10,000 15,000 20,000</td>
</tr>
<tr>
<td>3/16/2021</td>
<td>-12 -16 -12</td>
</tr>
<tr>
<td>3/30/2021</td>
<td>-25 -35 -49</td>
</tr>
<tr>
<td>4/13/2021</td>
<td>-39 -54 -75</td>
</tr>
<tr>
<td>4/27/2021</td>
<td>-54 -81 -101</td>
</tr>
<tr>
<td>5/9/2021</td>
<td>-68 -96 -124</td>
</tr>
</tbody>
</table>

- Under each expansion scenario, a decrease in the cumulative number of COVID-19 deaths on specific dates with respect to the status quo scenario was projected to be:

<table>
<thead>
<tr>
<th>Date</th>
<th>Status Quo Scenario + 10k Extra Doses of Pfz &amp; Mod (wkly) + the Following Numbers of J &amp; J Vaccines (wkly):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 10,000 15,000 20,000</td>
</tr>
<tr>
<td>3/16/2021</td>
<td>-2 0 -2</td>
</tr>
<tr>
<td>3/30/2021</td>
<td>-2 -3 -3</td>
</tr>
<tr>
<td>4/13/2021</td>
<td>-2 -7 -10</td>
</tr>
<tr>
<td>4/27/2021</td>
<td>-3 -10 -16</td>
</tr>
<tr>
<td>5/9/2021</td>
<td>-12 -20 -26</td>
</tr>
</tbody>
</table>

- More intense vaccination than the status quo is expected to decrease hospitalizations and deaths in the next three months. However, the magnitude of the decrease is small, ≤ 3 dozen. Importantly, it is expected that the COVID-19 infection continues to spread. Therefore, social distancing and other COVID-19 protection measures (for example, mask-wearing) must continue – should they be relaxed, a “during vaccination surge” will occur and should be expected in the late April-early May period.
Section 1:

Trends of COVID-19 Cases, Deaths, Hospitalizations, and Vaccinations in Jefferson County, Kentucky
Figure 1: Total Covid-19 Cases and Deaths in Jefferson County KY by Feb. 9, 2021

Note: Authors calculations using the New York Times Data (link)
Figure 2: Confirmed Active Covid-19 Hospitalizations in Jefferson County KY by Feb. 9, 2021 (7-Day Moving Average)

Notes: Authors’ calculations using the data from the Kentucky Health Information Exchange (KHIE), reported on March 1, 2021.
Figure 3: Number of Vaccines Administered in Jefferson County KY by Feb. 27, 2021 (7-Day Moving Average)

Notes: Authors’ calculations using the data from the Kentucky Immunization Registry Data (KYIR).
Section 2:

A Brief Review of the Methodology
Epidemic Modeling Framework

An epidemic dynamics model (namely, a Susceptible-Exposed-Infectious-Recovered (SEIR) model) is adopted and estimated in this study. In the model, transmission through different phases of the COVID-19 epidemic (susceptible, exposed, infectious, hospitalized, vaccinated, recovered, and dead) is regulated with transmission and clinical dynamics parameters (Figure 4).

Key transmission parameters are the population, basic and effective reproduction factors, lengths of incubation periods, pre-infectiousness, infectiousness with and without symptoms, and vaccines’ efficacy rates and coverage.

Key clinical dynamics parameters are hospitalization rate among the symptomatic, time from onset of severe symptoms to hospitalization, length of hospital stay, fatality rate among the hospitalized, recovery time among the hospitalized, the time from hospitalization to death.

This study assumes that those who recover after contracting the virus will not become infected again. In addition, it is assumed that vaccinated people will recover and not contract the coronavirus.

Data

Information on the epidemic model’s parameters was collected from the following sources:

- Jefferson County COVID-19 Case and Fatality Database (LMPHW)
- KHIE COVID-19 Hospitalization Database (KHIE)
- Jefferson County Immunization Registry (KYIR)
- Systematic Review of COVID-19 Literature

The values of the epidemic model’s parameters used in this study are presented in Table 2.

Stages of Estimation

An SEIR model without a vaccination compartment was fitted to the trends of hospitalization and deaths in Jefferson County, Kentucky, from the beginning of COVID-19 in the county (early-March 2020) to the beginning of vaccination (mid-
December 2020). The fitted model’s predictions for all variables were used as initial values for another SEIR model with a vaccination compartment.

The latter model was used to project COVID-19 hospitalizations and deaths under eight different vaccination scenarios in two steps (Table 2 and Figure 5). In the first step, the epidemic model was calibrated to parallel the vaccination trend under each scenario (Figure 6). In the second step, hospitalizations and deaths were projected (Figures 7 and 8).

**Limitations**

Recent KHIE hospitalization reports show that active COVID-19 hospitalizations have been decreasing in the county. However, there is a significant delay (about four weeks) until the hospitalizations reports are complete. In this study, we assumed that hospitalizations remain on the average of the last two weeks before the start of the projection period (i.e., 10 February 2021) until the differential effects of various vaccination scenarios are apparent. If the recent decline in hospitalization is persistent over time, then this study’s results need to be modified. However, we do not expect that the differential effects of the vaccination scenarios (in comparison to the status quo scenario) be significantly different from what was estimated in this study.

All three vaccines (Pfizer, Moderna, and Johnson & Johnson) were combined in this study. Pfizer and Moderna require two doses, but Johnson & Johnson requires one dose. Also, the recommended timing between the two doses of Pfizer and Moderna vaccines is different: 21 days versus 28 days, respectively. In this study:

- It was assumed that second doses of Pfizer and Moderna vaccines are injected on time for all individuals (This is the reason for modeling only dose one trends in this study). This is a realistic assumption because 75% of the vaccinated individuals in Jefferson County received their second dose on time (i.e., in 28 days or less, 95% in 31 days or less).
- For all three vaccines, a common 21−35 day period was the estimated time from administering the first dose to attaining maximum immunity. If the second doses of Pfizer and Moderna vaccines are injected on time, and a 7−14 day period for the administration of the second dose to the maximum immunity is allowed, then the first-dose-to-max-immunity period of the Pfizer, Moderna, and Johnson & Johnson vaccines are 28−35 days, 35−42 days, and 7−14 days, respectively. Therefore, this study overestimated the administration-to-max-immunity period for Johnson & Johnson vaccine.
It was assumed that Johnson & Johnson starts distributing its vaccines on March 3, 2021. It was also assumed that it takes the company four weeks to reach its maximum production capacity, which was presumed to be 10,000, 15,000, or 20,000 doses a week for Jefferson County. Pfizer and Moderna took six weeks to reach their current level of vaccine supply for distribution. The results of this study will change if the speed of the production of the Johnson & Johnson vaccine is more rapid or slower than was assumed.

It was assumed that population contact rates and mobility remain constant during the projection period (February 10 to May 9, 2020). If the contact and mobility rates change over the period, the results will be affected accordingly.

It was implicitly assumed that contact rates among the vaccinated and non-vaccinated individuals in the community are identical. This may not be a realistic assumption because the initial phases of vaccination focus on specific groups (stratified by age and occupation). It is likely that the projected trends are overestimating the expected trends if the contact rate among the vaccinated groups is lower than the rate is among others.
Figure 4: The Conceptual Framework Used for Modeling Covid-19 Pandemic in Jefferson County, Kentucky: a Susceptible-Exposed-Infectious-Recovered (SEIR) Model

Susceptible -> Exposed

Exposed -> Vaccination, Pre-Symptomatic Period, Infectious with No Symptoms, Infectious with Mild Symptoms, Infectious with Severe Symptoms, Hospitalized, Dead

Vaccination -> Recovered

Pre-Symptomatic Period -> Recovered

Infectious with No Symptoms -> Recovered

Infectious with Mild Symptoms -> Recovered

Infectious with Severe Symptoms -> Hospitalized

Hospitalized -> Recovered

Dead -> Recovered
Table 1: Transmission and Clinical Parameters Used in the SEIR Model

<table>
<thead>
<tr>
<th>Parameters Extracted from the Literature:</th>
<th>Median</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of Infections That Are Asymptomatic(^{2-5})</td>
<td>43%</td>
<td>30%</td>
<td>50%</td>
</tr>
<tr>
<td>Incubation Period (Days)(^{6-9})</td>
<td>3.5</td>
<td>2.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Pre-Symptomatic Period (Days)(^{10-12})</td>
<td>1.5</td>
<td>1.1</td>
<td>2.5</td>
</tr>
<tr>
<td>Infectious Period for Asymptomatic Infections (Days)(^{13,14})</td>
<td>7.0</td>
<td>4.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Vaccine Effectiveness in Preventing Hospitalization(^{15,20})</td>
<td>95%</td>
<td>90%</td>
<td>100%</td>
</tr>
<tr>
<td>Administration to Maximum Immunization Period(^{15-20})</td>
<td>28</td>
<td>21</td>
<td>35</td>
</tr>
</tbody>
</table>

| Parameters Extracted from the KHIE and Jefferson County Person-Level Data: |        |
|------------------------------------------|--------|-------------|-------------|
| Infectious Period for Mildly Symptomatic Infections (Days)\(^{21-23}\) | 15.0   | 8.0         | 21.0        |
| Infectious Period for Severely Symptomatic Infections (Days) | 5.0    | 2.0         | 8.0         |
| Proportion of Symptomatic Infections That Required Hospitalization\(^{24,25}\) | 12.6%  | 7.6%        | 17.6%       |
| Duration of Hospital Stay of Those Who Recovered from the Infection (Days) | 6.0    | 3.0         | 9.0         |
| Duration of Hospital Stay of Those Who Died of the Infection (Days) | 18.0   | 10.0        | 27.0        |
| Fatality Rate Among Hospitalizations | 7.0%   | 4.0%        | 10.0%       |

Notes: For each parameter of the SEIR model, a range of values from the lower bound to the upper bound was used in simulations. The parameters in the first section of the table were extracted from the literature. The parameters of the second section are calculated by the authors using two separate person-level data sources: (1) Kentucky Health Information Exchange (KHIE) COVID-19 hospitalization data, collected and compiled at the Kentucky Cabinet for Health and Family Services (CHFS); (2) Jefferson County COVID-19 Case and Fatality Data, collected and compiled at the Louisville Metro Department of Public Health and Wellness (LMPHW). The information on infectious periods is not available in the KHIE data and is extracted from Jefferson County data and used for all regions. A lower bound is the 25\(^{th}\) quantile of the parameter value distribution in the related subsample, and an upper bound is the 75\(^{th}\) quantile.
<table>
<thead>
<tr>
<th>Scenario</th>
<th>Scenario #</th>
<th>Scenario Description</th>
<th>Period</th>
<th>Herd Immunity Date if the Scenario Continues*</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Status Quo Scenario: Pfizer and Moderna without Johnson &amp; Johnson</td>
<td>1</td>
<td>- 30,000 doses of Pfizer and Moderna every week (covering all second doses and 15,000 first doses)</td>
<td>Feb 10 - May 9</td>
<td>October 9, 2021</td>
</tr>
<tr>
<td>Pfizer and Moderna with Johnson &amp; Johnson</td>
<td>2</td>
<td>- 30,000 doses of Pfizer and Moderna every week (covering all second doses and 15,000 first doses)</td>
<td>Feb 10 - May 9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>- Johnson &amp; Johnson will provide either of the following numbers of doses every week:</td>
<td>Mar 3 - May 9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 10,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 15,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>- 20,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expanded Status Quo: More Pfizer and Moderna without Johnson &amp; Johnson</td>
<td>5</td>
<td>- 30,000 doses of Pfizer and Moderna every week (covering all second doses and 15,000 first doses)</td>
<td>Feb 10 - Mar 2</td>
<td>August 7, 2021</td>
</tr>
<tr>
<td></td>
<td>- 40,000 doses of Pfizer and Moderna every week (covering all second doses and 20,000 first doses)</td>
<td>Mar 3 - May 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>More Pfizer and Moderna with Johnson &amp; Johnson</td>
<td>6</td>
<td>- 30,000 doses of Pfizer and Moderna every week (covering all second doses and 15,000 first doses)</td>
<td>Feb 10 - Mar 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- 40,000 doses of Pfizer and Moderna every week (covering all second doses and 20,000 first doses)</td>
<td>Mar 3 - May 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Johnson &amp; Johnson will provide either of the following numbers of doses every week:</td>
<td>Mar 3 - May 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20,000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* The herd immunity is assumed to be the date at which 75% of the population either received both doses of the Pfizer and Moderna vaccines or a Johnson & Johnson vaccine dose.
Figure 5: Illustration of the Vaccination Scenarios (Number of First Doses)

(Date)

(Number of First Doses Administered)

- Actual (wkly)
- 15k Pfz & Mod (wkly)
- 15k Pfz & Mod, 10k J&J (wkly)
- 15k Pfz & Mod, 15k J&J (wkly)
- 15k Pfz & Mod, 20k J&J (wkly)
- 20k Pfz & Mod (wkly)
- 20k Pfz & Mod, 10k J&J (wkly)
- 20k Pfz & Mod, 15k J&J (wkly)
- 20k Pfz & Mod, 20k J&J (wkly)
Section 3:

Simulation Results
Figure 6: The SEIR Model’s Fit of the Vaccination Scenarios (Number of First Doses)

Note: Each vaccination trend in the two figures is the median of 300 simulations. The trends for all 300 simulations are presented in Appendix Figure 1.
Figure 7: Projections of Active Hospitalizations under the Vaccination Scenarios (Number of First Doses, All Second Doses Covered)

Note: Each hospitalization trend in the two figures is the median of 300 simulations. The trends for all 300 simulations are presented in Appendix Figure 2.
Figure 8: Projections of Total Deaths under the Vaccination Scenarios (Number of First Doses, All Second Doses Covered)

Note: Each death trend in the two figures is the median of 300 simulations. The trends for all 300 simulations are presented in Appendix Figure 3.
Summary of Projection Results

This report investigated the simulated effect of several vaccination scenarios on COVID hospitalizations and deaths in Jefferson County, Kentucky.

• **Scenarios:** Eight scenarios were considered. First, it was assumed that the status quo scenario (~30,000 doses of Pfizer and Moderna vaccines distributed and administered every week) would continue without Johnson & Johnson’s vaccine. Then, three scenarios of the addition of Johnson & Johnson’s vaccine (10,000, 15,000, and 20,000 weekly) were considered. Next, an expansion over the status quo scenario (~40,000 doses of Pfizer per week) was considered with and without Johnson & Johnson’s vaccine scenarios.

• **Projection Period:** February 10 to May 9, 2021 (three months)

• **Key Projection Assumptions:**
  - The focus of this study is to show the differential effects of different intensities of vaccination. Therefore, it is assumed that COVID-19 hospitalizations were plateaued in the two weeks before the projection period. If the recent decreasing trends in hospitalizations continued, then this study’s results need to be modified. However, we expect that differential effects of the vaccination scenarios be different from what was estimated in this study.
  - All second doses will be administrated on time.
  - First-dose-administration to the maximum-immunity period for a vaccine, regardless of its manufacturer, is between 21 and 35 days.
  - Contact rate and mobility in the population do not change during the study period.
  - The contact rate among the vaccinated and non-vaccinated individuals is not different.

• **Projected Decrease in the Number of Active COVID-19 Hospitalizations on Specific Dates under Vaccination Expansion Scenarios versus the Status Quo Scenario:**

<table>
<thead>
<tr>
<th>Date</th>
<th>Status Quo Scenario + 0</th>
<th>10,000</th>
<th>15,000</th>
<th>20,000</th>
<th>Status Quo Scenario + 10k Extra Doses of Pfz &amp; Mod (wkly) + 0</th>
<th>10,000</th>
<th>15,000</th>
<th>20,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/16/2021</td>
<td>-</td>
<td>-12</td>
<td>-16</td>
<td>-12</td>
<td>-8</td>
<td>-16</td>
<td>-19</td>
<td>-26</td>
</tr>
<tr>
<td>3/30/2021</td>
<td>-</td>
<td>-25</td>
<td>-35</td>
<td>-49</td>
<td>-14</td>
<td>-42</td>
<td>-55</td>
<td>-66</td>
</tr>
<tr>
<td>4/13/2021</td>
<td>-</td>
<td>-39</td>
<td>-54</td>
<td>-75</td>
<td>-12</td>
<td>-58</td>
<td>-83</td>
<td>-99</td>
</tr>
<tr>
<td>4/27/2021</td>
<td>-</td>
<td>-54</td>
<td>-81</td>
<td>-101</td>
<td>-26</td>
<td>-86</td>
<td>-110</td>
<td>-132</td>
</tr>
<tr>
<td>5/9/2021</td>
<td>-</td>
<td>-68</td>
<td>-96</td>
<td>-124</td>
<td>-36</td>
<td>-99</td>
<td>-126</td>
<td>-152</td>
</tr>
</tbody>
</table>
- Projected Decrease in the Cumulative Number of COVID-19 Deaths on Specific Dates under Vaccination Expansion Scenarios versus the Status Quo Scenario:

<table>
<thead>
<tr>
<th>Date</th>
<th>Status Quo Scenario + the Following Number of J &amp; J Vaccines (wkly):</th>
<th>Status Quo Scenario + 10k Extra Doses of Pfz &amp; Mod (wkly) + the Following Numbers of J &amp; J Vaccines (wkly):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>10,000</td>
</tr>
<tr>
<td>3/16/2021</td>
<td>-</td>
<td>-2</td>
</tr>
<tr>
<td>3/30/2021</td>
<td>-</td>
<td>-2</td>
</tr>
<tr>
<td>4/13/2021</td>
<td>-</td>
<td>-2</td>
</tr>
<tr>
<td>4/27/2021</td>
<td>-</td>
<td>-3</td>
</tr>
<tr>
<td>5/9/2021</td>
<td>-</td>
<td>-12</td>
</tr>
</tbody>
</table>
References


Supplementary Figures:

Detailed Results
Appendix Figure 1: Vaccination Trends (Scenarioed vs. Simulated)

- **15k Pfz & Mod (wkly)**
- **15k Pfz & Mod, 10k J&J (wkly)**
- **15k Pfz & Mod, 15k J&J (wkly)**
- **15k Pfz & Mod, 20k J&J (wkly)**
Appendix Figure 2: Projected Active Hospitalizations under Simulated Vaccination Trends (Actual vs. Simulated)

15k Pfz & Mod (wkly)

15k Pfz & Mod, 10k J&J (wkly)

15k Pfz & Mod, 15k J&J (wkly)

15k Pfz & Mod, 20k J&J (wkly)
Appendix Figure 3: Projected Total Deaths under the Simulated Vaccination Trends (Actual vs. Simulated)

- 15k Pfz & Mod (wkly)
- 15k Pfz & Mod, 10k J&J (wkly)
- 15k Pfz & Mod, 15k J&J (wkly)
- 15k Pfz & Mod, 20k J&J (wkly)