Abstract

Introduction: The trends in the numbers of active hospitalizations and fatalities caused by the COVID-19 in Jefferson County, Kentucky, were projected over the period May 7 to August 2020.

Methods: The projections provided in this report are from a susceptible-exposed-infectious-recovered (SEIR) model. The model was calibrated using the COVID-19 transmission dynamics parameters from relevant literature and clinical dynamics parameters from the county's data. The model was used for measuring the impact of public health policy interventions designed to contain the infection. The policy was modeled by its intervention day and impact on the transmission of the virus such that the resulted fatalities resembled those observed in Jefferson County.

Results: By May 6, 2020, there were 1,557 cases and 109 COVID-19 deaths in Jefferson County. The average age of deceased individuals was 76.5 years—76% of them had a previous medical condition, and 28% were African American. Among the hospitalized, 53% were admitted to the ICU, and 43% used a ventilator. The model’s status quo scenario, which produced the observed fatalities in the county, was identified assuming that the transmission of the virus was reduced by 70% with a policy intervention on April 7. Projections based on the status quo showed 91 active hospitalizations and 147 total fatalities, on average, on May 14. By June 4, the average number of active hospitalizations were projected to decrease to 61, but total fatalities to increase to 195, assuming a 70% reduction in transmission of the virus was maintained since the implementation of the policy intervention. By late August, the average number of active hospitalizations and total fatalities were projected to be 12 and 269, respectively.

Conclusion: Had the county practiced weaker containment strategies, it would have been more effective measures can make a manageable early-June opening more likely.

Introduction

Most known epidemic models that are recently developed study the trends of the spread of COVID-19 and the related hospitalization and deaths at the national and state levels, hence, do not provide projections at local/county level. [1-8] Since a significant amount of preparedness efforts takes place at the county-level, projecting COVID-19 trends at the local level is necessary. The attempts to provide county-level projections have been twofold. In one, state-level projections are simply adjusted for counties' population. As such, county-level projections are mass-produced. [9,10] In the other, an epidemic model is specifically calibrated for the county of interest. Such studies are scarce [11,12], and this analysis can be categorized among them since it characterizes an epidemic model specifically for Jefferson County, Kentucky.
Jefferson County includes the city of Louisville, and has an estimated population of 767,000 people and 310,000 households in July 2019. [13] The county may be more vulnerable to the COVID-19 impact than a typical U.S. county because of its lower-than-average health and economic status. The median household income in the county was about 10% lower than the national average in the past five years, and the poverty rate was 30% higher than the national rate in 2019. [13] Jefferson County also ranks in the lowest tertile of life expectancy and the highest tertile of deaths associated with respiratory diseases, compared to other counties in the US. [14] Among the 120 Kentucky counties, Jefferson County ranks 47 and 37 in terms of health risk factors and health outcomes, respectively. [15]

In this study, the trends in the numbers of active hospitalizations and fatalities caused by the COVID-19 in Jefferson County, Kentucky, were projected over the period May 7 to August 20, 2020.

**Methods**

*Epidemic Modeling*

A classic deterministic model of epidemic dynamics, namely, a susceptible-exposed-infectious-recovered (SEIR) model, was used in this analysis. [16] The model classifies a population into four connected compartments: the susceptible, the exposed, the infectious, and the recovered. The susceptible population includes individuals who could be infected by the virus. In this model, those who live in Jefferson County are the susceptible population.

The exposed or latently infected population is a segment of the susceptible population that has infectious contact with infected individuals. The size of the exposed population depends on the size of the susceptible population, the average number of daily contacts per individual, and the likelihood of transmission of the virus per contact. The latter two form the basic reproduction factor ($R_0$) of the virus. The exposed individuals go through an incubation period until they become infectious. Depending on the severity of their symptoms, infectious individuals follow two paths. Those with severe symptoms are hospitalized, but those with moderate, mild, or no symptoms will recover without the need for hospitalizations. Hospitalized individuals either recover or pass away. (Figure 1) The transmission through these four
compartments is regulated with transmission dynamics parameters (namely, population, the basic reproduction factor, and the periods of incubation and infectiousness). This study’s assumptions on the SEIR model’s transmission dynamics parameters are presented in Table 1. The selected values for the basic reproduction factor [17-22], incubation period [22-24], and infection period [17,24-27], and infection period [17,24-27] accord with the recent COVID-19 literature.

Table 1 also presents this study’s assumptions on the SEIR model’s clinical dynamics. All clinical parameters (except for the case fatality rate [CFR]) were extracted from the Jefferson County COVID-19 case and fatalities data compiled at the Louisville Metro Department of Public Health & Wellness (LMPHW). The CFR in Jefferson County is 7.0%, remarkably greater than the rates reported in the related literature. [28-33] Suspecting the high rate is due to limited testing in the county, a 2% rate that is confirmed by existing literature was used. The Jefferson County-specific values selected for the recovery time [26], time to hospitalization [17,27], hospitalization rate [34,35], length of hospital stay [36,37], and the time from incubation to death [17,27,36,37] fall in the ranges suggested by the related literature.

Scenario Building
The model allows for measuring the effect of a public health policy intervention to contain an infection. The policy is characterized by an intervention day and the policy’s degree of strength at reducing the transmission of the virus. The intervention day can be set closer to or further from the emergence of the first reported infection and death in the susceptible population. The strength of the intervention is determined by the decrease in the number of transmissions by one person.

The intervention tool was used to calibrate the model for the Jefferson County deaths. In the first edition of this analysis, [38] two potential intervention scenarios that would have approximately led to the number of deaths in the county by April 16 were considered. In one, the intervention day was set on April 7, 2020 (two weeks after the governor of Kentucky's stay-home order issued on March 25), [39] it was assumed that the intervention (representing all containment measures taken by the public authority, businesses and people) led to a 70% decrease in the transmission of COVID-19. In the other intervention scenario, the intervention day was set a week earlier on March 31, 2020, and it was assumed that the intervention led to a 65% decrease in the transmission of the virus. These two scenarios (status quo scenarios henceforth) approximately represented the observed COVID-19 fatalities in Jefferson County by April 16.

Under each of the two status quo scenarios, four potential alternatives that reflect containment methods that would have been weaker or stronger in terms of reducing the transmission of the virus were examined. The transmission decrease scenarios allowed for discussing where the county’s COVID-19 status (in terms of the numbers of hospitalizations and deaths) would have been if weaker or stronger containment had practiced.

This updated analysis benefited from the observations of COVID-19 cases, hospitalizations, and deaths in Jefferson County for 20 extra days after the first analysis was conducted. Hence, it allowed for assessing the credibility of the two status quo scenarios. The assessment led to the dismissal of the status quo scenario that assumed an intervention became effective on March 31. Scenarios for the decrease of the virus’s transmission after the intervention on April 7 are presented in Table 2.

Caveats
The projections provided in this analysis are highly dependent on the assumptions of basic reproduction number R0 (that is inherent to this novel disease for which the authors’ have no control over), the real intervention day in the sense of when it became an effective intervention, and the presumed percentage decrease in transmission after the interven-

| Table 2. Adjustment of the policy components of the epidemic model |
|---|---|
| **Policy Component** | **Assigned Value** |
| Intervention Day | March 25<sup>5</sup> |
| The date of stay-home executive order: | Two weeks after the stay-home order, April 7 |
| The decrease in transmission after the intervention: | Scenarios: (1) Low: 60% and 65% (2) Middle: 70% (3) High: 75% and 80% |
| (a correlate of R<sub>t</sub>, with lower R<sub>t</sub> for higher percent decreases in transmission) | |
| Calibration: The percentage decrease in the transmission of the virus was calibrated for the observed Jefferson County deaths. As a result, the benchmark decrease in the transmission was determined 70% |
Table 3. Characteristics of COVID-19 positive cases and deaths from COVID-19 in Jefferson County (KY) as of May 6th, 2020.

| Time from symptoms to report form in days, median (IQR) among symptomatic cases with known symptom onset, n=1,184 | Cases (n=1,557) | Deaths (n=109) |
|---|---|---|
| - Symptomatic cases (n=1,253) with unknown symptom onset date, n (%) | 9.4 (IQR: 5, 12) | 69 (5.5%) |

Input Statistics from the data:

| Case Fatality Rate (%) | 7.0% |
|---|---|
| Time from symptoms to death in days, median (IQR) among deaths with symptom onset date information, n=93 | 10 (6, 17) |

- Deaths (n=109) with missing onset date, n (%) | 16 (14.7%) |

Hospitalization proportion, n (%) | 529 (34.0%) |

- Cases with unknown hospitalization status, n (%) | 192 (12.3%) |

Length of hospital stay in days, median (IQR), among the hospitalized with known dates, n=419 | 5 (3, 9) |

- Hospitalized patients (n=529) with unknown admission or discharge date, n (%) | 110 (20.8%) |

Time from symptoms to hospitalizations in days, median (IQR), among the hospitalized with known dates, n=393 | 6 (3, 9) |

- Hospitalized patients (n=529) with unknown admission or onset date, n (%) | 136 (25.7%) |

Symptom duration in days, median (IQR), among symptomatic cases with known start and resolution dates, n=339 | 11 (7, 16) |

- Symptomatic cases (n=1,253) with unknown symptom onset or resolution dates, n (%) | 914 (72.9%) |

Case Characteristics (n=1,557)

| Age in years, mean (IQR; min:max) | 54.3 (40, 68; 0:103) | 76.5 (67, 88; 35:103) |
|---|---|---|
| Race, n (%)* | | |
| - White | 762 (48.9) | 66 (60.6) |
| - African American | 405 (26.0) | 31 (28.4) |
| - Asian | 95 (6.1) | 6 (5.5) |
| - Other or Unknown | 295 (19.0) | 6 (5.5) |
| Sex, n (%) | | |
| Male (sex=1) | 668 (45.3) | 52 (48.2) |
| Female (sex=2) | 807 (54.7) | 56 (51.9) |
| Missing | 82 | 1 |
| With COVID-19 symptom(s), n (%) | | |
| No symptoms | 1,253 (80.5) | 100 (91.7) |
| Missing | 119 (7.6) | 3 (2.8) |

Among those hospitalized COVID-19 cases (n=529):

| Admitted to ICU, n (%)* | 140 (28.2) | 50 (52.6) |
|---|---|---|
| Mechanical Ventilator, n (%)* | 101 (20.8) | 41 (43.2) |

Medical Conditions

| Previous Medical Condition, n (%) | 754 (48.4) | 83 (76.2) |
|---|---|---|
| History of CVD, n (%) | 488 (31.1) | 80 (73.4) |
| Diabetic, n (%) | 330 (21.2) | 48 (44.0) |

* The percentages were calculated among those without missing data for the variable.
### Table 3, cont.

| Condition                        | Cases (n=1,557) | Deaths (n=109) |
|----------------------------------|-----------------|----------------|
| Neurological Condition, n (%)    | 192 (12.3)      | 48 (44.0)      |
| -Missing                         | 571 (36.7)      | 30 (27.5)      |
| Chronic Lung Disease, n (%)      | 281 (18.1)      | 30 (27.5)      |
| -Missing                         | 526 (33.8)      | 30 (27.5)      |
| Past or Current Smoker, n (%)    | 317 (20.4)      | 27 (24.8)      |
| -Missing                         | 413 (26.5)      | 30 (27.5)      |
| Renal Disease, n (%)             | 122 (7.8)       | 21 (19.3)      |
| -Missing                         | 570 (36.6)      | 32 (29.4)      |
| Immunocompromised, n (%)         | 82 (5.3)        | 10 (9.2)       |
| -Missing                         | 595 (38.2)      | 37 (33.9)      |
| History of Chronic Liver Disease, n (%) | 22 (1.4) | 2 (1.8) |
| -Missing                         | 589 (37.8)      | 36 (33.0)      |

#### Symptoms

| Symptom                          | Cases (n=1,557) | Deaths (n=109) |
|----------------------------------|-----------------|----------------|
| Cough, n (%)                     | 939 (60.3)      | 70 (64.2)      |
| -Missing                         | 236 (15.2)      | 16 (14.7)      |
| Fever, n (%)                     | 724 (46.5)      | 58 (53.2)      |
| -Missing                         | 277 (17.8)      | 22 (20.2)      |
| Subjective Fever, n (%)          | 603 (38.7)      | 48 (44.0)      |
| -Missing                         | 380 (24.4)      | 22 (20.2)      |
| Shortness of Breath, n (%)       | 640 (41.1)      | 73 (70.0)      |
| -Missing                         | 298 (19.1)      | 7 (6.4)        |
| Myalgia, n (%)                   | 595 (38.2)      | 25 (22.9)      |
| -Missing                         | 334 (21.5)      | 29 (26.6)      |
| Chills, n (%)                    | 523 (33.6)      | 20 (18.4)      |
| -Missing                         | 350 (22.5)      | 28 (25.7)      |
| Headache, n (%)                  | 494 (31.7)      | 6 (5.5)        |
| -Missing                         | 344 (22.1)      | 31 (28.4)      |
| Abnormal Chest X-Ray, n (%)      | 396 (25.4)      | 82 (75.2)      |
| -Missing                         | 399 (25.6)      | 7 (6.4)        |
| Pneumonia, n (%)                 | 377 (24.2)      | 79 (72.5)      |
| -Missing                         | 426 (27.4)      | 13 (11.9)      |
| Diarrhea, n (%)                  | 344 (22.1)      | 12 (11.0)      |
| -Missing                         | 368 (23.6)      | 31 (28.4)      |
| Nausea and Vomiting, n (%)       | 332 (21.3)      | 17 (15.6)      |
| -Missing                         | 355 (22.8)      | 24 (22.0)      |
| Runny nose, n (%)                | 271 (17.4)      | 8 (7.3)        |
| -Missing                         | 403 (25.9)      | 29 (26.6)      |
| Sore Throat, n (%)               | 235 (15.1)      | 4 (3.7)        |
| -Missing                         | 404 (26.0)      | 31 (28.4)      |
| Abdominal Pain, n (%)            | 185 (11.9)      | 13 (11.9)      |
| -Missing                         | 401 (25.8)      | 31 (28.4)      |
| Acute Respiratory Distress, n (%) | 99 (6.4)       | 33 (30.3)      |
| -Missing                         | 496 (31.8)      | 22 (20.2)      |
tion. As more Jefferson County data become available, the relevance of the assumptions will be examined again.

**Results**

**Observed Jefferson County Data**

By May 6, 2020, there were 1,557 reported cases and 109 COVID-19 deaths in Jefferson County. ([Table 3 and Figure 2](#))

On average, there was an estimated 9-day delay from the start date of symptoms to the reporting date in the data. The CFR was 7.0%, a much higher rate than what is observed elsewhere, because of the lack of widespread testing, which has a much greater impact on the underreporting of cases relative to more accurate fatality data.

The average age of deceased individuals was 76.5 years and the average age of reported cases was 54.3 years. About 76% of the deceased had a previous medical condition, 73% had a history of cardiovascular disease, 44% had diabetes, and 44% had a neurological condition. ([Table 3](#))

While about 22% of the Jefferson County residents are African Americans, [13] about 26% of the cases and 28% of the deaths were among the county’s African American residents. ([Table 3](#)) White Americans constitute 72% of the county’s population, [13] but the rates of COVID positives and COVID deaths among them were 49% and 61%, respectively ([Table 3](#)).

The number of active hospitalizations rapidly increased from March 20th to March 30th then plateaued until April 27,
Table 4. Projected hospitalizations and fatalities under different scenarios of decrease in transmission. [40]
The status quo scenario is highlighted. (Assumption: April 7 was the effective intervention day and others listed in Table 2.)

| Dates   | Total Projected Numbers of Active Hospitalizations | Total Projected Numbers of Fatalities |
|---------|--------------------------------------------------|--------------------------------------|
|         | % Decrease in Transmission | % Decrease in Transmission |
| 2020    | 60  | 65  | 70  | 75  | 80  | 60  | 65  | 70  | 75  | 80  |
| 30-Apr  | 156 | 137 | 114 | 100 | 86  | 116 | 110 | 101 | 97  | 91  |
| 7-May   | 166 | 136 | 105 | 86  | 68  | 149 | 138 | 122 | 114 | 105 |
| 14-May  | 176 | 131 | 91  | 67  | 47  | 196 | 173 | 147 | 133 | 118 |
| 21-May  | 183 | 125 | 81  | 55  | 35  | 233 | 207 | 164 | 144 | 125 |
| 28-May  | 192 | 120 | 69  | 42  | 23  | 284 | 231 | 183 | 156 | 132 |
| 4-Jun   | 198 | 115 | 61  | 34  | 17  | 324 | 255 | 195 | 162 | 136 |
| 11-Jun  | 207 | 109 | 52  | 25  | 11  | 379 | 284 | 209 | 170 | 139 |
| 18-Jun  | 213 | 104 | 46  | 20  | 8   | 421 | 305 | 218 | 174 | 141 |
| 25-Jun  | 220 | 98  | 39  | 15  | 5   | 480 | 331 | 229 | 178 | 142 |
| 2-Jul   | 226 | 94  | 34  | 12  | 4   | 525 | 350 | 236 | 180 | 143 |
| 9-Jul   | 232 | 88  | 29  | 9   | 3   | 587 | 374 | 244 | 183 | 144 |
| 16-Jul  | 237 | 84  | 25  | 7   | 2   | 635 | 391 | 249 | 185 | 144 |
| 23-Jul  | 243 | 79  | 21  | 6   | 1   | 700 | 412 | 255 | 186 | 144 |
| 30-Jul  | 246 | 75  | 19  | 4   | 1   | 749 | 427 | 258 | 187 | 145 |
| 6-Aug   | 251 | 70  | 16  | 3   | 1   | 816 | 446 | 263 | 188 | 145 |
| 13-Aug  | 253 | 67  | 14  | 3   | 0   | 867 | 460 | 266 | 188 | 145 |
| 20-Aug  | 255 | 62  | 12  | 2   | 0   | 919 | 477 | 269 | 189 | 145 |

Figure 4. The Benchmark Scenario, resembling the current status in Jefferson County. The patterns of active hospitalization and deaths if the presumed intervention on April 7 decreased transmission by 70% (other assumptions are presented in Table 2). [40]
Figure 5. The status if stronger social distancing were practiced. The patterns of active hospitalization and deaths if the presumed intervention on April 7 decreased transmission by 75% (other assumptions are presented in Table 2). [40]

Figure 6. The patterns of active hospitalization and deaths if the presumed intervention on April 7 decreased transmission by 80% (other assumptions are presented in Table 2). [40]
Figure 7. The status if weaker social distancing were practiced. The patterns of active hospitalization and deaths if the presumed intervention on April 7 decreased transmission by 65% (other assumptions are presented in Table 2). [40]

Figure 8. The patterns of active hospitalization and deaths if the presumed intervention on April 7 decreased transmission by 60% (other assumptions are presented in Table 2). [40]
Figure 9. Projected weekly numbers of active hospitalizations under different social distancing scenarios. (The status quo: the intervention on April 7 decreased transmission by 70%.)

Figure 10. Projected numbers of total fatalities by week under different social distancing scenarios. (The status quo: the intervention on April 7 decreased transmission by 70%.)
from then a decreasing trend was apparent (Figure 3). Among the hospitalized deaths, 53% were admitted to the ICU, and 43% used a ventilator, while among all reported cases, 28% were admitted to the ICU, and 21% used a ventilator (Table 3).

Projections
Projections based on the status quo simulation (i.e., continuing with current public and private containment policies that were assumed to become effective at reducing transmission by 70% on April 7, 2020) (Table 2), showed 91 active (current) hospitalizations and 147 total fatalities, on average, on May 14.

On June 4, July 2, and August 20, had the same policies been in place and continued to reduce transmission by 70% since April 7, the average number of active hospitalizations were projected to continuously decrease to 61, 34, and 12, respectively (Table 4 and Figure 4).

Under the status quo assumptions, especially that the same policies been in place and continued to reduce transmission by 70% since April 7, the rate of increase in deaths due to COVID-19 will significantly decrease. On June 4, July 2, and August 20, for example, the total number of COVID-19 deaths were projected to be 195, 236, and 269, respectively. (Table 4 and Figure 4) [40]

Interpretation
If stronger containment methods (including personal precautions, population management such as social distancing, workplace personnel management, and patient placement) would have been used from the presumed intervention day (April 7) and if those methods would have decreased the transmission of the virus by an additional 10%, then the average numbers of active hospitalizations and total fatalities may have decreased to 17 and 136, respectively, by June 4. (Table 4) On the other hand, if weaker containment methods were used from the presumed intervention days and virus transmission would have increased by an additional 10% (i.e., from 70% to 60%), the projected average numbers of active hospitalizations and total fatalities may have increased to 198 and 324, respectively, by June 4. (Table 4)

Even under a 10% weaker social distancing scenario, only 255 beds are needed to handle the “surge.” (Table 4) Therefore, of more than 3600 hospital beds in Louisville, an estimated 3345 hospital beds could be brought back into clinical use and used as Non-COVID.

Figures 5 and 6 show the potential patterns had the measures taken to decrease the transmission of the virus from April 7 were more effective (or stronger social distancing were practiced). Figures 7 and 8 show the potential patterns had the measures taken to decrease the transmission of the virus from April 7 were less effective (or weaker or stronger social distancing were practiced). Figures 9 and 10, respectively, show the trends in hospitalizations and deaths under social distancing scenarios that are weaker or stronger than the status quo scenario.

Discussion
If weaker social distancing than the current status were practiced in Jefferson County, then the county would have been in an unstable path with increased hospitalization and fatality trends. On the other hand, had Jefferson County practiced stronger containment strategies, it could have had even fewer hospitalizations and deaths and further flattened the curve, which is the objective of non-pharmaceutical interventions in the absence of treatment or vaccine. Stronger social distancing, even with re-opening, will flatten the curve by decreasing the large clusters at any point or short period of time.

Since less than 10% of the approximately 3600 total hospital beds in Louisville will be needed, even with 10% weaker social distancing than is present with the status quo scenario, the vast majority of the hospital beds being held in reserve for COVID-19 patients could be brought back into general clinical use without concern for exceeding the needed bed capacity. Using a rapid point-of-care test for SARS-CoV-2 to identify all infected persons prior to hospital admission would further improve medical care in the community and help the economy begin to return to normal. According to the results presented in this analysis, stronger measures can still make a manageable early-June opening more likely (Figures 5 and 6). Stronger efforts in the future to reduce transmission of the virus could include more extensive testing with consistent and rapid tracing (with quarantine as appropriate) of all contacts of recognized cases. These efforts should allow for much more effective containment of spread than is available at present and could allow for an earlier date of gradual relaxation of current restrictions.

Decreasing the current social distancing measures without efforts in regard to testing, isolating, and contact tracing can move the county to an unstable status, resembling the trends presented in Figures 7 and 8. The rapid implementation and effectiveness of any social distancing measures, personal protection measures, and systems to quickly contact trace
to decrease transmission after a contact has been made are crucial to limit the transmission of the virus.

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