University of Louisville Journal of Respiratory Infections

ORIGINAL RESEARCH

Projecting the COVID-19 Weekly Deaths and Hospitalizations for Jefferson County, Kentucky

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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 20, 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 on an upward path with increased hospitalization and fatality trends. Therefore, decreasing the current social distancing measures without efforts regarding testing, isolating, and contact tracing can move the county to an unstable status. Had Jefferson County practiced stronger containment strategies, it could more safely plan open in early June. Still taking newer and even more effective measures can make a manageable early-June opening more likely.

Recommended Citation:
Karimi, Seyed M.; DuPre, Natalie; Mckinney, W. Paul; Little, Bert B.; Patel, Naiya; Moyer, Sarah (2020). "Projecting the COVID-19 Weekly Deaths and Hospitalizations for Jefferson County, Kentucky," *The University of Louisville Journal of Respiratory Infections*: Vol. 4, Iss. 1, Article 44.

Received Date: May 14, 2020

Accepted Date: May 27, 2020

Published Date: July 8, 2020

Funding Source: The author(s) received no specific funding for this work.

Conflict of Interest: All authors declared no conflict of interest in relation to the main objective of this work.

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.

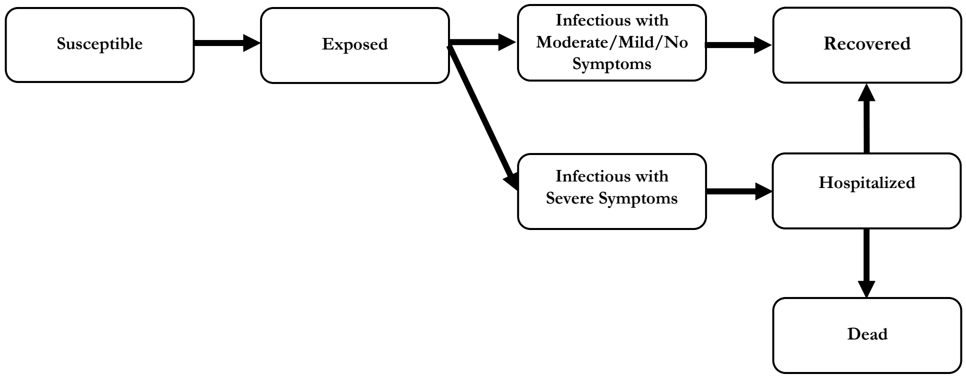

Figure 1. Components of the SEIR model.

Table 1. Assumptions on the transmission and clinical dynamics parameters of the SEIR model

Parameter	Assigned Value
Transmission Dynamics	
Jefferson County population	767×10^3
Basic reproduction number (R_0)	2.7 (Calibrated for Jefferson County Deaths)
Length of the incubation period	5.2 days (Literature)
Duration of infectiousness	5.0 days (Literature)
Clinical Dynamics:	
Case fatality rate (CFR)	2%
Time from symptom onset to recovery for mild cases	11.10 days (Jefferson County Average)
Time from symptom onset to hospitalization for severe cases	6.00 days (Jefferson County Average)
Hospitalization rate	9.00% (Jefferson County Average)
Length of hospital stay	5.00 (Jefferson County Average)
Time from end of incubation to death	12.35 days (Jefferson County Average)

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

Table 2. Adjustment of the policy components of the epidemic model

Policy Component	Assigned Value
Intervention Day The date of stay-stay home executive order:	March 25[5]
The assumption on the effective intervention day:	Two weeks after the stay-home order, April 7
The decrease in transmission after the intervention: (a correlate of R_t, with lower R_t for higher percent decreases in transmission)	Scenarios: (1) Low: 60% and 65% (2) Middle: 70% (3) High: 75% and 80%
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%	

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] 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 3. Characteristics of COVID-19 positive cases and deaths from COVID-19 in Jefferson County (KY) as of May 6th, 2020.

	Cases (n=1,557)	Deaths (n=109)
Time from symptoms to report form in days, median (IQR) among symptomatic cases with known symptom onset, n=1,184	9.4 (IQR: 5, 12)	
- Symptomatic cases (n=1,253) with unknown symptom onset date, n (%)	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 (%)	1,253 (80.5)	100 (91.7)
No symptoms	185 (11.9)	6 (5.5)
-Missing	119 (7.6)	3 (2.8)
Among those hospitalized COVID-19 cases (n=529):		Among hospitalized deaths (n=95)
Admitted to ICU, n (%)*	140 (28.2)	50 (52.6)
-Missing	33	--
Mechanical Ventilator, n (%)*	101 (20.8)	41 (43.2)
-Missing	43	--
Medical Conditions		
Previous Medical Condition, n (%)	754 (48.4)	83 (76.2)
-Missing	367 (23.6)	24 (22.0)
History of CVD, n (%)	488 (31.1)	80 (73.4)
-Missing	490 (31.5)	19 (17.4)
Diabetic, n (%)	330 (21.2)	48 (44.0)
-Missing	498 (32.0)	16 (14.7)

* The percentages were calculated among those without missing data for the variable.

Table 3, cont.

	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		
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	495 (31.8)	22 (20.2)

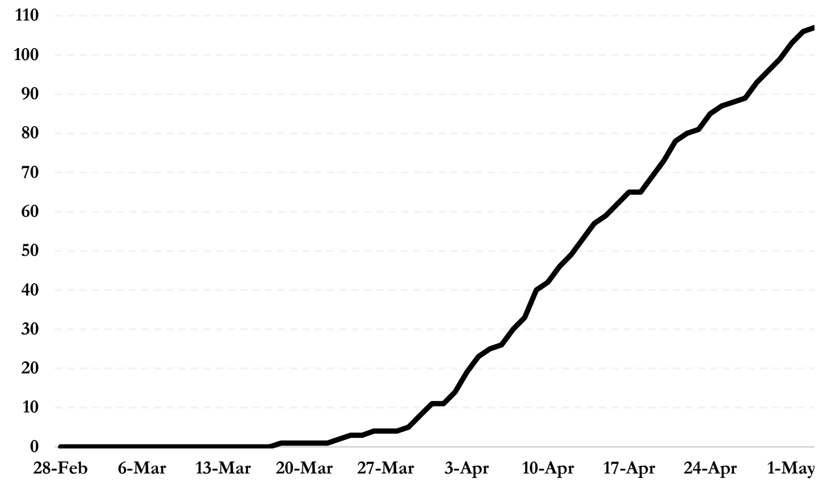

Figure 2. The cumulative number of deaths in Jefferson County, KY, by May 6, 2020.

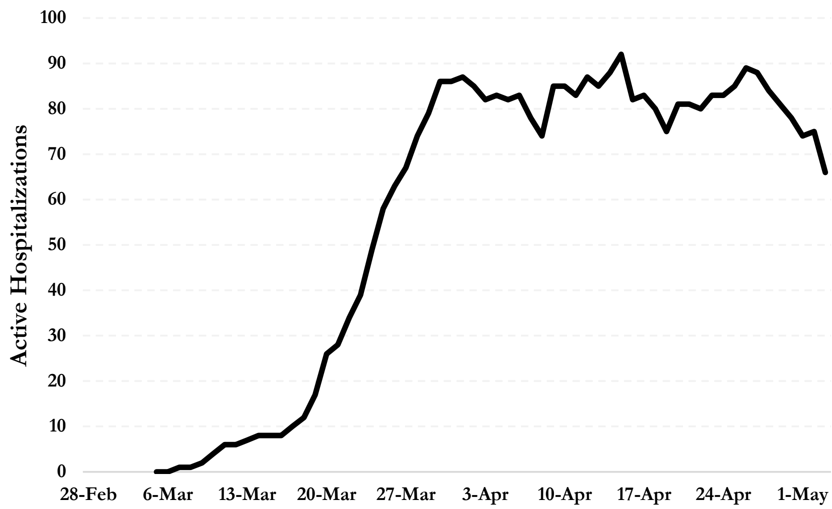

Figure 3. Number of active hospitalizations in Jefferson County, KY, by May 6, 2020 (the county's median length of stay in hospital is used in the calculations).

tion. As more Jefferson County data become available, the relevance of the acovidssumptions 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				
in	% 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

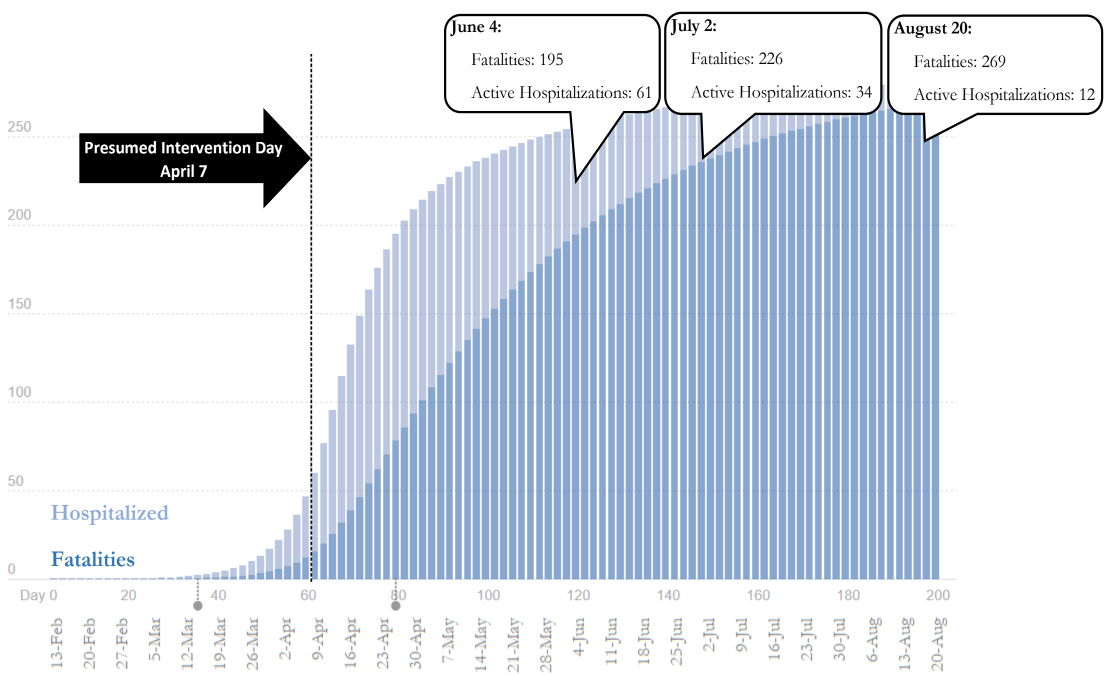

Figure 4. The Benchmark Scenario, resembling the current status in Jefferson County. The patterns of active hospitalization and deaths if the presumed intervention on April 7 decreased transmission by 70% (other assumptions are presented in Table 2). [40]

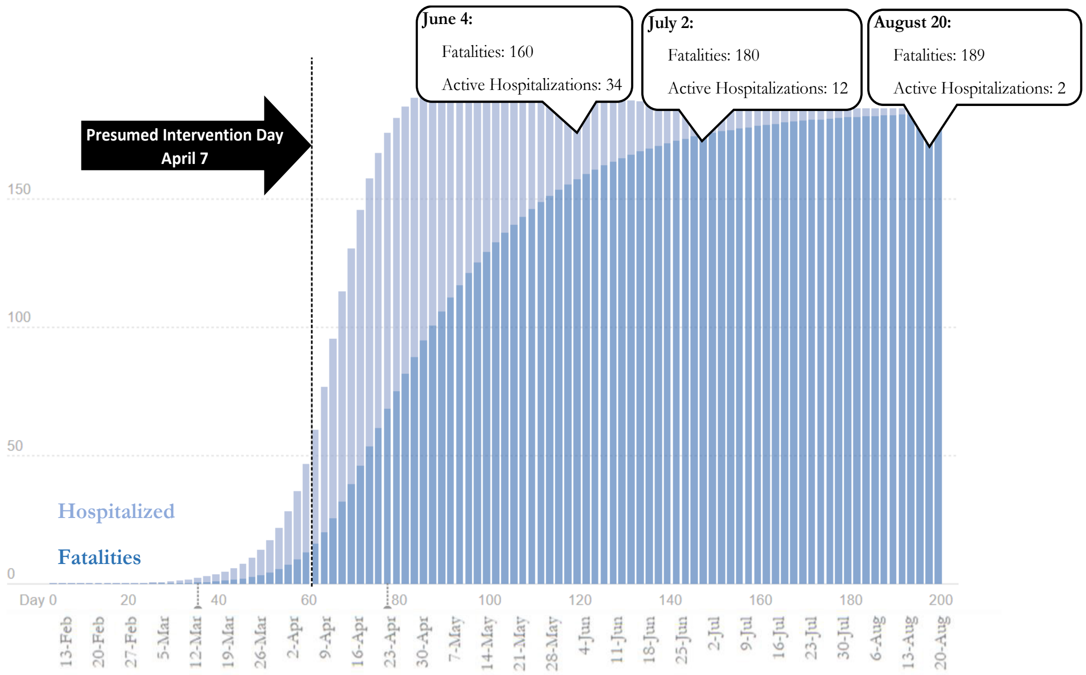

Figure 5. The status if stronger social distancing were practiced. The patterns of active hospitalization and deaths if the presumed intervention on April 7 decreased transmission by 75% (other assumptions are presented in Table 2). [40]

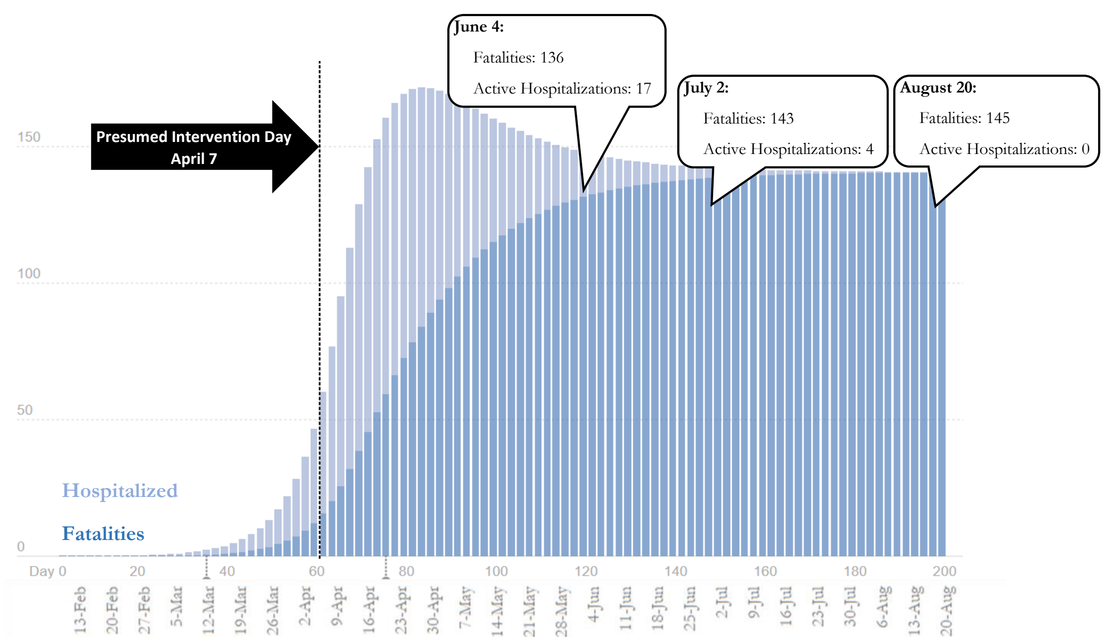

Figure 6. The patterns of active hospitalization and deaths if the presumed intervention on April 7 decreased transmission by 80% (other assumptions are presented in Table 2). [40]

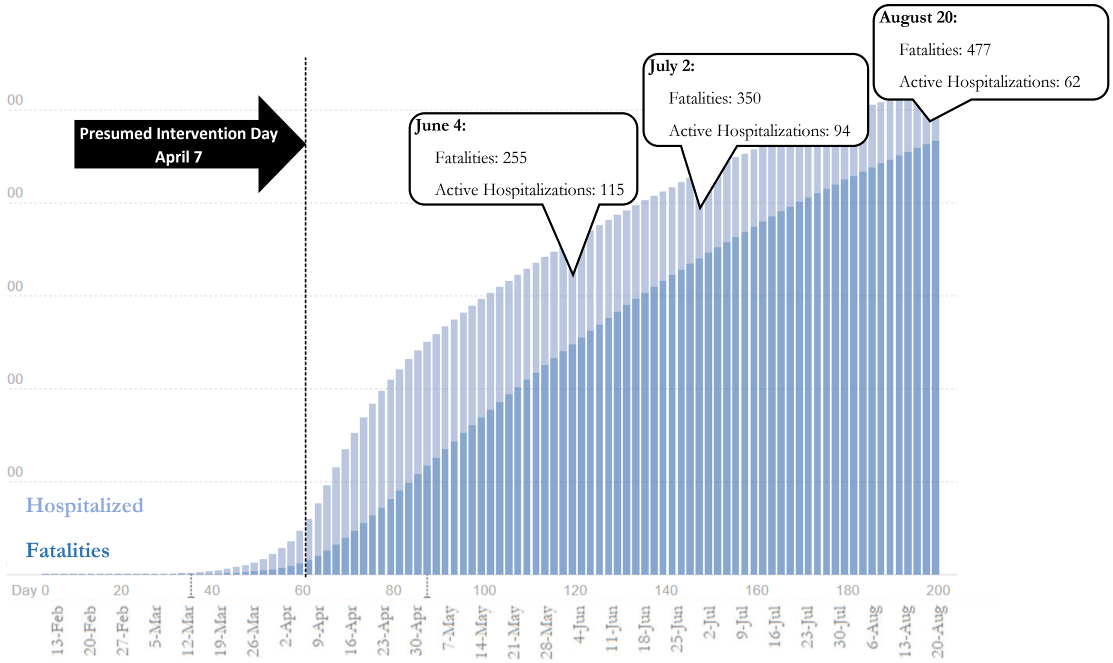

Figure 7. The status if weaker social distancing were practiced. The patterns of active hospitalization and deaths if the presumed intervention on April 7 decreased transmission by 65% (other assumptions are presented in Table 2). [40]

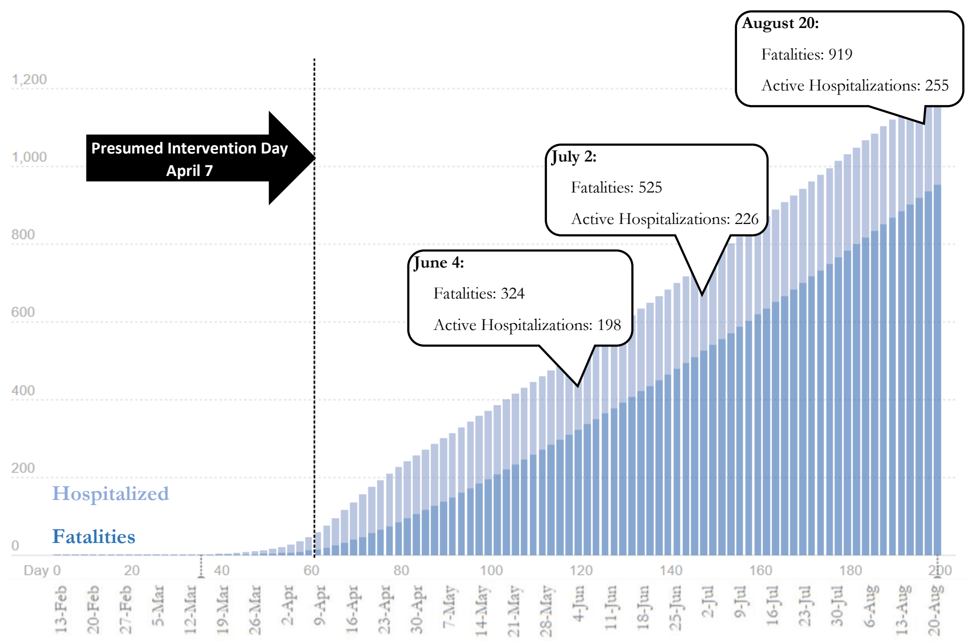

Figure 8. The patterns of active hospitalization and deaths if the presumed intervention on April 7 decreased transmission by 60% (other assumptions are presented in Table 2). [40]

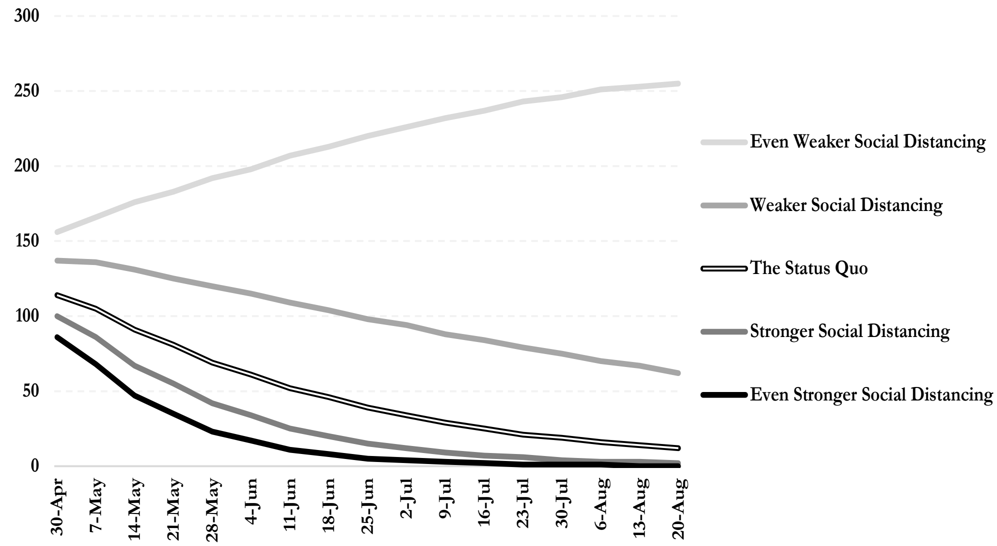

Figure 9. Projected weekly numbers of active hospitalizations under different social distancing scenarios. (The status quo: the intervention on April 7 decreased transmission by 70%.)

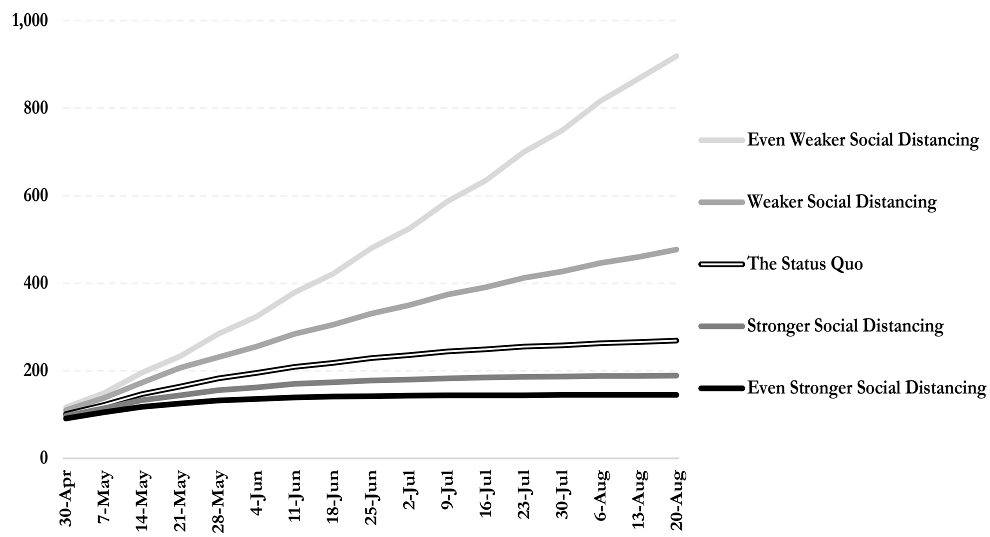

Figure 10. Projected numbers of total fatalities by week under different social distancing scenarios. (The status quo: the intervention on April 7 decreased transmission by 70%.)

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 tes for SARS-CoV-2 to identify all infected persons prior to hospital admission would further improve medical care in the community and help the economybegin 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.

References

1. COVID-19 Projections [Internet]. Institute for Health Metrics and Evaluation. 2020 [cited 2020 May 5]. Available from: https://covid19.healthdata.org/united-states-of-america
2. COVID-19 Forecasts. CDC [Internet]. Centers for Disease Control and Prevention. 2020 [cited 2020 May 5]. Available from: https://www.cdc.gov/coronavirus/2019-ncov/covid-data/forecasting-us.html
3. Bertsimas D. COVIDAnalytics [Internet]. MIT operations research center. 2020 [cited 2020 May 5]. Available from: https://www.covidanalytics.io/
4. Pei S, Shaman, J. Initial simulation of SARS-CoV2 spread and intervention effects in the continental U.S. medRxiv. 2020 Jan 1. doi:10.1101/2020.03.21.20040303.
5. COVID-19 Mortality Projections for US States [Internet]. The University of Texas Austin. 2020 [cited 2020 May 5]. Available from: https://covid-19.tacc.utexas.edu/projections/
6. Vespignani A. COVID-19 modeling in the United States [Internet]. GLEAM Project. 2020 [cited 2020 May 5]. Available from: https://covid19.gleamproject.org/#about
7. COVID-19 confirmed and forecasted case data [Internet]. Los Alamos National Laboratory. 2020 [cited 2020 May 5]. Available from: https://covid-19.bsvgateway.org/
8. Best R, Boice J. Where the latest COVID-19 models think we're headed — and why they disagree [Internet]. FiveThirtyEight. 2020 [cited 2020 May 5]. Available from: https://projects.fivethirtyeight.com/covid-forecasts/
9. Rubin D, Tasian G, Huang J. COVID-Lab: mapping COVID-19 in your community [Internet]. PolicyLab. The Children's Hospital of Philadelphia and The University of Pennsylvania. 2020 [cited 2020 May 5]. Available from: https://policylab.chop.edu/covid-lab-mapping-covid-19-your-community
10. COVID-19 forecast for United States – Hospital I.Q. [Internet]. Hospital I.Q. 2020 [cited 2020 May 5]. Available from: https://app.hospiq.com/covid19
11. King A, Ionides E, Breto C, Ellner S, Ferrari M, Kendall B, et al. Potential long-term intervention strategies for COVID-19 [Internet]. Statistical Inference for Partially Observed Markov Processes. 2020 [cited 2020 May 5]. Available from: http://covid-measures.stanford.edu/
12. Gerald JK. COVID-19 Forecast Model, Arizona and Pima County | Mel and Enid Zuckerman College of Public Health [Internet]. The University of Arizona. 2020 [cited 2020 May 5]. Available from: https://publichealth.arizona.edu/news/2020/covid-19-forecast-model
13. QuickFacts: Jefferson County, Kentucky [Internet]. U.S. Census Bureau. [cited 2020 May 5]. Available from: https://www.census.gov/quickfacts/fact/table/jeffersoncountykentucky/PST045219
14. County Profile: Jefferson County, Kentucky [Internet]. Institute for Health Metrics and Evaluation (IHME). 2020 [cited 2020 May 5]. Available from: http://www.healthdata.org/sites/default/files/files/county_profiles/US/2015/County_Report_Jefferson_County_Kentucky.pdf
15. Kentucky County Health Rankings & Roadmaps [Internet]. Robert Wood Johnson Foundation and Wisconsin Population Health Institute. 2020 [cited 2020 May 5]. Available from: https://www.countyhealthrankings.org/app/kentucky/2020/
16. Costa PJ. Applied Mathematics for the Analysis of Biomedical Data. Applied mathematics for the analysis of biomedical data. Hoboken, NJ, USA: John Wiley & Sons, Inc. 2017. http://doi.wiley.com/10.1002/9781119269540
17. Sanche S, Lin YT, Chonggang Xu, Ethan Romero-Severson, Nick Hengartner, Ruian Ke. High contagiousness and rapid spread of severe acute respiratory syndrome coronavirus 2. Emerging Infectious Disease Journal. 2020;26(7). https://doi.org/10.3201/eid2607.200282
18. Liu Y, Gayle AA, Wilder-Smith A, Rocklöv J. The reproductive number of COVID-19 is higher compared to SARS coronavirus. Journal of Travel Medicine. 2020 Mar 13;27(2):1–4. https://doi.org/10.1093/jtm/taaa021
19. Wang Y, You XY, Wang YJ, Peng LP, Du ZC, Gilmour S, et al. [Estimating the basic reproduction number of COVID-19 in Wuhan, China]. 2020 Mar 3;41(4):476–479. https://doi.org/10.3760/cma.j.cn112338-20200210-00086
20. Zhang, S, Diao, M, Yu, W, Pei, L, Lin, Z, Chen, D. Estimation of the reproductive number of novel coronavirus (COVID-19) and the probable outbreak size on the Diamond Princess cruise ship: a data-driven analysis. International Journal of Infectious Diseases. 2020 Apr;93:201–204, https://doi.org/10.1016/j.ijid.2020.02.033
21. Zhao, S, Lin, Q, Ran J, Musa SS, Yang G, Wang W, Lou Y, Gao D, Yang L, He D, et al. Preliminary estimation of the basic reproduction number of novel coronavirus (2019-nCoV) in China, from 2019 to 2020: A data-driven analysis in the early phase of the outbreak. International Journal of Infectious Diseases. 2020 Mar 1;92:214–217, https://doi.org/10.1016/j.ijid.2020.01.050
22. Lauer SA, Grantz KH, Bi Q, Jones FK, Zheng Q, Meredith HR, Azman AS, Reich NG, Lessler J. The incubation period of coronavirus disease 2019 (COVID-19) from publicly reported confirmed cases: estimation and application. Annals of Internal Medicine. 2020 May 5;172:577–582, https://doi.org/10.7326/M20-0504
23. Kucharski AJ, Russell TW, Diamond C, Liu Y, Edmunds J, Funk S, et al. Early dynamics of transmission and control

of COVID-19: a mathematical modelling study. The Lancet Infectious Diseases. 2020 May 1;20(5):553–558. https://doi.org/10.1016/S1473-3099(20)30144-4
24. Lauer SA, Grantz KH, Bi Q, Jones FK, Zheng Q, Meredith HR, et al. The incubation period of cronavirus disease 2019 (COVID-19) from publicly reported confirmed cases: estimation and application. Annals of Internal Medicine. 2020 May 5;172:577–582. https://doi.org/10.7326/M20-0504
25. Kissler SM, Tedijanto C, Goldstein E, Grad YH, Lipsitch M . Projecting the transmission dynamics of SARS-CoV-2 through the postpandemic period. Science, 2020 Apr 14. https://doi.org/10.1126/science.abb5793
26. Wölfel R, Corman VM, Guggemos W, Seilmaier M, Zange S, Müller MA, et al. Virological assessment of hospitalized patients with COVID-2019. Nature. 2020 Apr 1. https://doi.org/10.1038/s41586-020-2196-x
27. Han Y, Feng Z, Sun L, Ren X, Wang H, Xue Y, et al. A comparative-descriptive analysis of clinical characteristics in 2019-coronavirus-infected children and adults. Journal of Medical Virology. 2020 Apr 6. https://doi.org/10.1002/jmv.25835
28. Baud D, Qi X, Nielsen-Saines K, Musso D, Pomar L, Favre G. Real estimates of mortality following COVID-19 infection. Lancet Infect Dis. 2020 Mar;20(7):S1473-3099(20)30195-X. https://doi.org/10.1016/S1473-3099(20)30195-X PMID:32171390
29. Spychalski P, Błażyńska-Spychalska A, Kobiela J. Estimating case fatality rates of COVID-19. Lancet Infect Dis. 2020 Mar;31:S1473-3099(20)30246-2. https://doi.org/10.1016/S1473-3099(20)30246-2 PMID:32243815
30. Lipsitch M. Estimating case fatality rates of COVID-19. Lancet Infect Dis. 2020 Mar;31:S1473-3099(20)30245-0. https://doi.org/10.1016/S1473-3099(20)30245-0 PMID:32243813
31. Kim DD, Goel A. Estimating case fatality rates of COVID-19. Lancet Infect Dis. 2020 Mar;S1473-3099(20)30234-6. https://doi.org/10.1016/S1473-3099(20)30234-6 PMID:32243814
32. Baud D, Nielsen-Saines K, Qi X, Musso D, Pomar L, Favre G. Authors' reply. Lancet Infect Dis. 2020 Mar;20(7):775–6. https://doi.org/10.1016/S1473-3099(20)30255-3.
33. Basu A. Estimating The Infection Fatality Rate Among Symptomatic COVID-19 Cases In The United States: Study estimates the COVID-19 infection fatality rate at the US county level. Health Aff. 2020 Jul 1:10-377.
34. Ferguson N, Laydon D, Nedjati Gilani G, Imai N, Ainslie K, Baguelin M, Bhatia S, Boonyasiri A, Cucunuba Perez ZU, Cuomo-Dannenburg G, Dighe A. Report 9: Impact of non-pharmaceutical interventions (NPIs) to reduce COVID19 mortality and healthcare demand. 2020 Mar 16.
35. Verity R, Okell LC, Dorigatti I, Winskill P, Whittaker C, Imai N, et al. Estimates of the severity of coronavirus disease 2019: a model-based analysis. Lancet Infect Dis. 2020 Jun;20(6):669–77. https://doi.org/10.1016/S1473-3099(20)30243-7 PMID:32240634
36. Tindale L, Coombe M, Stockdale JE, Garlock E, Lau WY, Saraswat M, et al. Transmission interval estimates suggest pre-symptomatic spread of COVID-19. medRxiv. 2020 Jan 1.
37. Gaythorpe K, Imai N, Cuomo-Dannenburg G, Baguelin M, Bhatia S, Boonyasiri A, et al. Report 8: Symptom progression of COVID-19. 2020 Mar 11. DOI: 10.25561/77344
38. Karimi SM, DuPre N, McKinney P, Little B, Moyer S. Projecting the COVID-19 weekly deaths, infections, and hospitalizations for Jefferson County, Kentucky [Internet]. Louisville Metro Department of Public Health & Wellness (LMPHW) and the University of Louisville School of Public Health and Information Sciences (SPHIS). 2020 May 4. Available from: http://louisville.edu/sphis/documents-and-pdfs/JCCOVID19PredictionWeek1Report5120distribution.pdf
39. Beshear A. Executive Order- State of Emergency [Internet]. Commonwealth of Kentucky. 2020 Mar 25. Available from: https://governor.ky.gov/attachments/20200325_Executive-Order_2020-257_Healthy-at-Home.pdf
40. Calculations in this document were done with the Epidemic Calculator [Internet]. [accessed May 6, 2020]. Available from: https://gabgoh.github.io/COVID/index.html