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

May 10, 2020

Last date with actual data:	**May 6, 2020**
Predicted for:	**Every week from April 30 to August 20**

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Key Messages

- Social distancing measures taken in Jefferson County were justified.

- We have the hospital capacity to reopen the economy carefully and slowly.

- The projections inform the Louisville Metro Department of Public Health & Wellness to evaluate the number of staff needed to do proper investigations and contact tracing.

- The projections also inform the Louisville Metro hospital system on the number of expected hospitalizations as the current status or weaker or stronger social distancing is pursued.

Abstract

Objective: We projected the trends in the numbers of active hospitalizations and fatalities caused by the Covid-19 in Jefferson County, Kentucky, over the period April 20 to August 20, 2020.

Methods: The projections provided in this report are from an epidemic dynamics model called the ***s***usceptible-***e***xposed-***i***nfectious-***r***ecovered (SEIR) model. We calibrated the model using the Covid-19 transmission dynamics parameters from relevant literature and clinical dynamics parameters from the county's data. We used the model for measuring the impact of public health policy interventions designed to contain the infection. We modeled policy 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 black. 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 transmission of the virus was reduced by 70% with 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.

Conclusions: (1) Had Jefferson County practiced stronger containment strategies, it could more safely plan open in early June. Taking newer and even more effective measures can make a manageable early-June opening more likely. (2) Stronger containment efforts in the future to reduce transmission of the virus could include more extensive testing together with consistent tracing (quarantine as appropriate) of all contacts of recognized cases. (3) These efforts should allow for much more effective containment of spread than is currently present and could allow for an earlier date of gradual relaxation of current restrictions. (4) If we had practiced weaker social distancing than the current status, we would have been in an unstable path with increased hospitalization and fatality trends. Decreasing the current social distancing measures without efforts regarding testing, isolating, and contact tracing can move us to an unstable status which can be catastrophic. (5) The rapid implementation and effectiveness of social distancing measures, personal protection measures, testing, and systems to quickly contact trace to decrease transmission after a contact has been made are crucial to limit the transmission of the virus. The rates of hospitalization suggest that only 250 are needed to handle the "surge" under good social distancing compliance. Point of care (POC) rapid testing should be used before any hospitalization. This provides better medical care to the community and brings hospital beds back online that will likely not be needed under a surge if we prudently practice social distancing.

1. Introduction

Jefferson County includes the city of Louisville, which has an estimated population of 767,000 people and 310,000 households in July 2019.[1] 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.[1] 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.[2] Among the 120 Kentucky counties, Jefferson County ranks 47 and 37 in terms of health risk factors and health outcomes, respectively.[3]

We projected the trends in the numbers of active hospitalizations and fatalities caused by the Covid-19 in Jefferson County, KY, over the period April 20 to August 20, 2020.

2. Methods

Epidemic Modeling

We used a classic deterministic model of epidemic dynamics called the ***s***usceptible-***e***xposed-***i***nfectious-***r***ecovered (SEIR) model.[4] The model classifies a population into four connected compartments: the **s**usceptible, the **e**xposed, the **i**nfectious, and the **r**ecovered. 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 includes those who have acquired the virus but are not transmitting it. The infectious population is a subset of the exposed who are actively transmitting the virus. The recovered population is a subset of the infectious population who recovered and are no longer infectious. 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). Our assumptions on the SEIR model's transmission dynamics parameters are presented in Table 1. The selected values for the basic reproduction factor (R_0), incubation period, and infection period accord with the recent Covid-19 literature.

Table 1 also presents our 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 LMPHW. The CFR in Jefferson County is 7.0%, remarkably greater than the rate elsewhere. We suspect the high rate is due to limited testing in the county and use a rate that is confirmed by existing 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.

We used the intervention tool to calibrate the model for the Jefferson County deaths. In the first report, we considered two potential intervention scenarios that would have approximately led to the number of deaths in the county by April 16. In one, we set the intervention day on April 7, 2020 (two weeks after the governor's stay-home order issued on March 25)[5] and 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, we set the intervention day a week earlier on March 31, 2020, but assumed that the intervention led to a 65% decrease in transmission of the virus. We labeled these two scenarios *status quo* scenarios, approximately representing the observed Covid-19 fatalities in Jefferson County. The scenarios allowed for a period of adjustment (compliance) after the governor's March 25 stay-home order.

Under each of the two *status quo* scenarios, we considered four potential alternatives that reflect containment methods that would have been weaker or stronger in terms of reducing transmission of the virus. Therefore, we discussed where the Jefferson County Covid-19 status in terms of the numbers of hospitalizations and deaths would have been if we had practiced weaker or stronger containment (*i.e.*, social distancing, contact tracing, testing, and isolation of cases) strategies.

This current report benefited from the observations of Covid-19 cases and deaths in Jefferson County for 20 extra days after the first report was prepared. Hence, we could assess the credibility of the two *status quo* scenarios. The assessment led us to dismiss one of the *status quo* scenario (which assumed an intervention became effective on March 31) and to update the projections based on the other *status quo* scenario that assumed an intervention became effective on April 7. The considered scenarios for the decrease of the virus's transmission after the intervention are similar to those in the previous report (Table 2).

Caveats

The projections provided in this analysis are highly dependent on the assumptions of basic reproduction number R_0 (that is inherent to this novel disease for which we 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 intervention. The assumptions will be examined as more Jefferson County data become available.

3. Results

Observed Data

By May 6, 2020, there were 1,557 reported cases and 109 Covid-19 deaths in Jefferson County (Table 3 and Figure 1). 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%, which is perceived as an overestimation of the actual case fatality rate because of the lack of widespread testing. 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. About 49% and 26% of Covid-19

cases were among white and black residents, respectively; about 61% and 28% of deaths were among the white and black residents, respectively (Table 3).

The number of active hospitalizations rapidly increased from March 20th to March 30th then plateaued until April 27, from then a decreasing trend was apparent (Figure 2). 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 hospitalizations and 147 total fatalities, on average, on May 14. On June 4, had the same policies been in place and continued to reduce transmission by 70% since April 7, then the average number of active hospitalizations were projected to decrease to 61, but total fatalities were projected to increase to 195 by June 4. By late August, the average numbers of active hospitalizations and total fatalities were projected to be 12 and 269, respectively (Table 4 anf Figure 3).

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 they 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).

Figures 4 and 5 show the potential patterns had the measures taken to decrease the transmission of the virus from April 7 were more effective (or had we practiced stronger social distancing).

Figures 6 and 7 show the potential patterns had the measures taken to decrease the transmission of the virus from April 7 were less effective (or had we practiced weaker social distancing).

Figures 8−9, respectively, show the trends in hospitalizations and deaths under social distancing scenarios that are weaker or stronger than the *status quo* scenario.

4. Conclusions

Had Jefferson County practiced stronger containment strategies, it could more safely plan open in early June. Taking newer and even more effective measures can make a manageable early-June opening more likely.

Stronger efforts in the future to reduce transmission of the virus could include more extensive testing together 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.

If we had practiced weaker social distancing than the current status, we would have been in an unstable path with increasing hospitalization and fatality trends.

Decreasing the current social distancing measures without efforts in regard to testing, isolating, and contact tracing can move us to an unstable status.

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.

Of more than 3600 hospital beds in Louisville, an estimated 3350 hospital beds could be brought back into clinical use and used as Non-Covid. Point of care (POC) rapid Covid testing should be used before any hospital admission. This would improve medical care in the community and help begin to return the economy to normal.

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Table 1: Assumptions the epidemic model used in this analysis

Policy Component	Assigned Numbers
Transmission Dynamics:	
Population[1]	767,000 (Jefferson County population)
Basic reproduction number (R_0)[6-10]	2.7
Length of incubation period[11-13]	5.2 days
Duration patient is infectious[6,14-16]	5 days
Clinical Dynamics:	
Case Fatality Rate (CFR)[17-21]	2%
Time from end of incubation to death	12.35 days (Jefferson County average)
Length of hospital stay	5 days (Jefferson County average)
Recovery time for mild cases	11 days (Jefferson County average)
Hospitalization rate	9% (Jefferson County average)
Time to hospitalization	6 days (Jefferson County average)

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

Policy Component	Assigned Numbers
Intervention Day	
The date of stay-stay home executive order:	March 25[5]
Assumption on the effective intervention day:	Two weeks after the stay-home order, April 7
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%	

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)
-Black	405 (26.0)	31 (28.4)
-Asian	95 (6.1)	6 (5.5)
-Other or Unknown	295 (19.0)	6 (5.5)

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)
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)
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)

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)
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)

Table 4: Projected hospitalizations and fatalities under different scenarios of decrease in transmission[22]
(Assumption: April 7 was the effective intervention day and others listed in Table 2)
The *status quo* scenario is highlighted

Dates in 2020	Total Projected Numbers of **Active Hospitalizations** % Decrease in Transmission						Total Projected Numbers of **Fatalities** % Decrease in Transmission				
	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 1: The cumulative number of deaths in Jefferson County, KY, by May 6, 2020

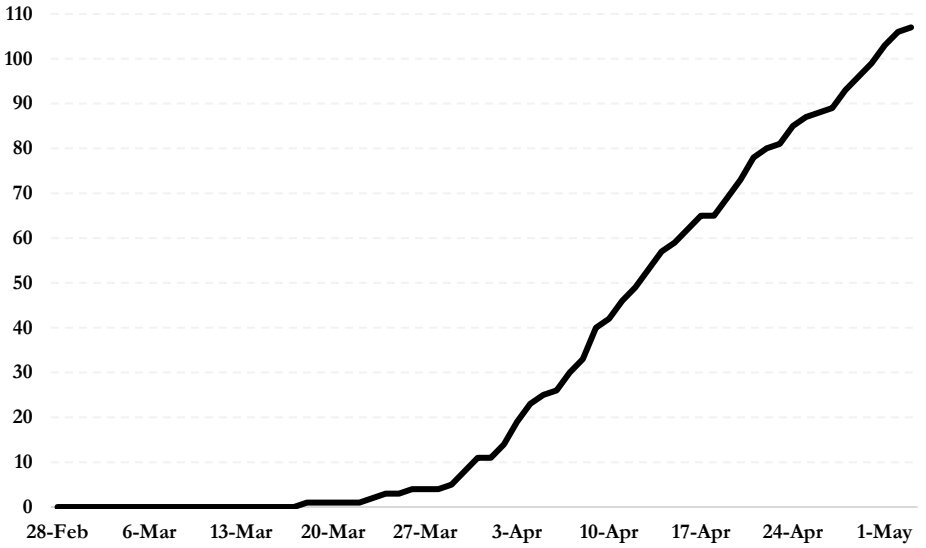
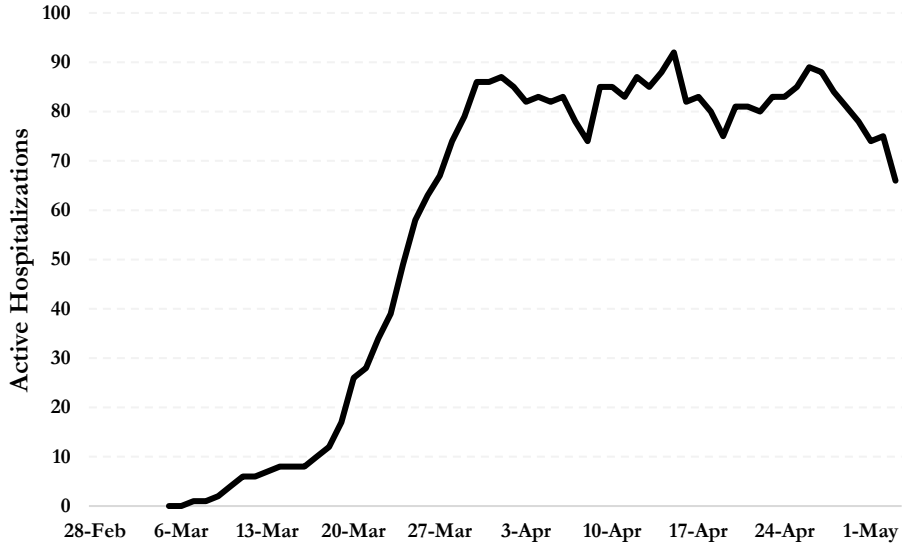
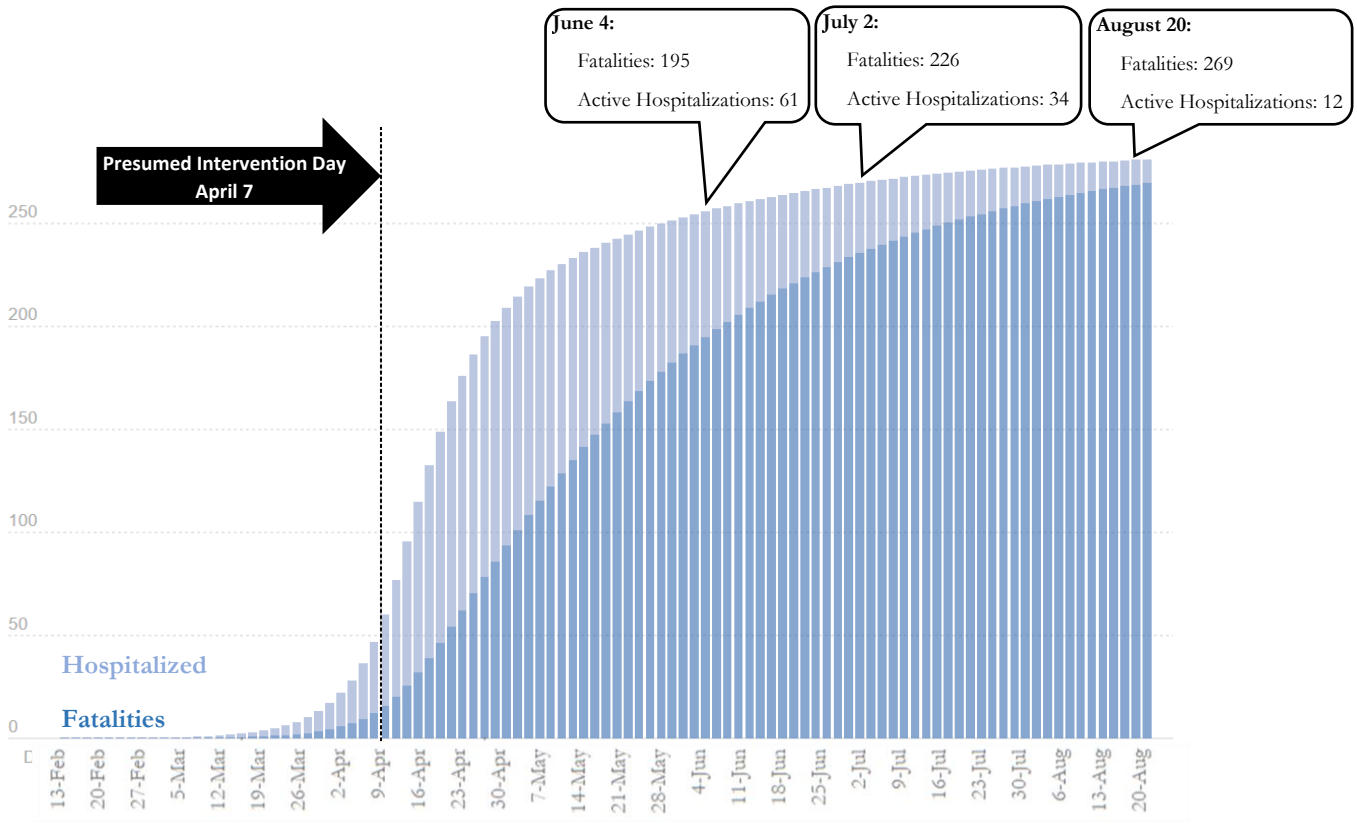


Figure 2: Number of active hospitalizations in Jefferson County, KY, by May 6, 2020 (the county's median length of stay in hospital is used in the calculations)



The Benchmark Scenario, resembling the current status in Jefferson County

Figure 3: 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)[22]



The status if we had practiced stronger social distancing practices

Figure 4: 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)

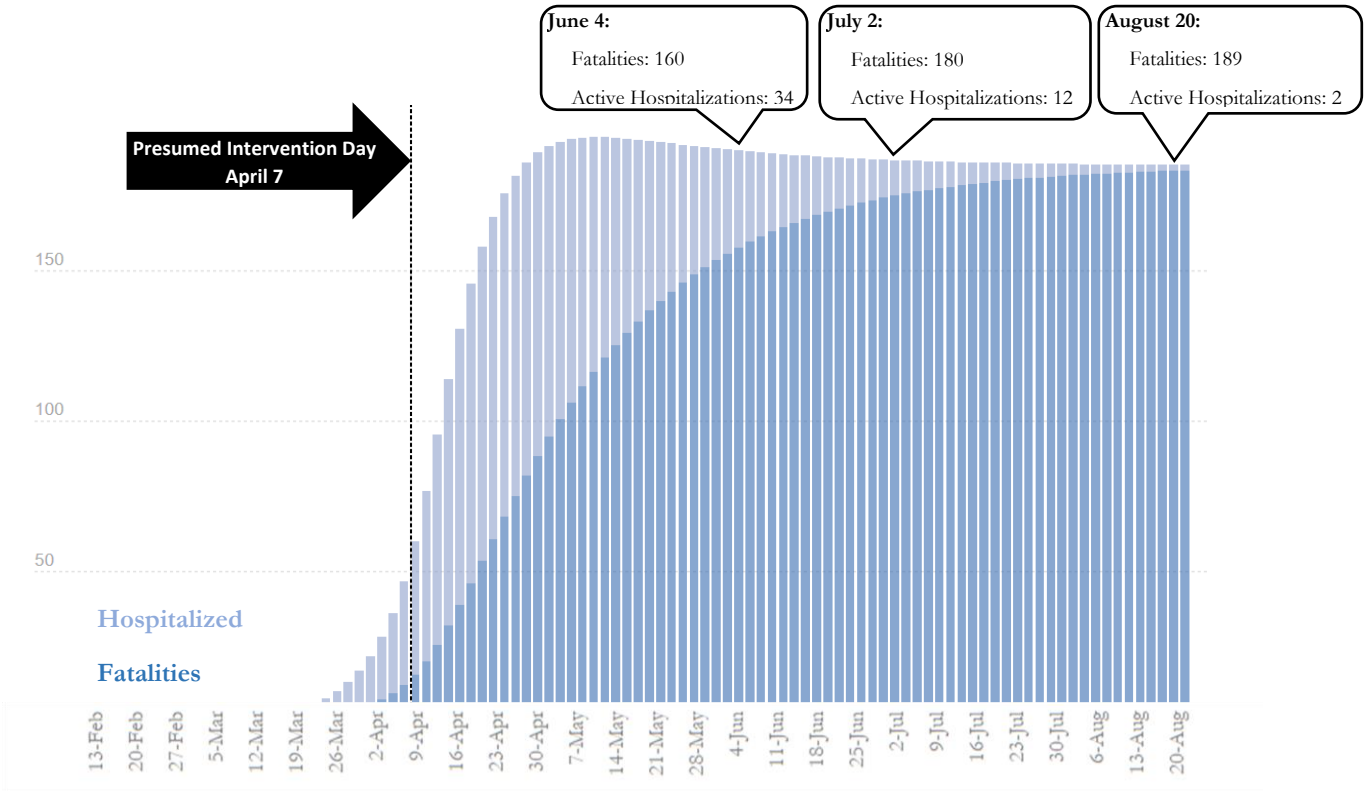
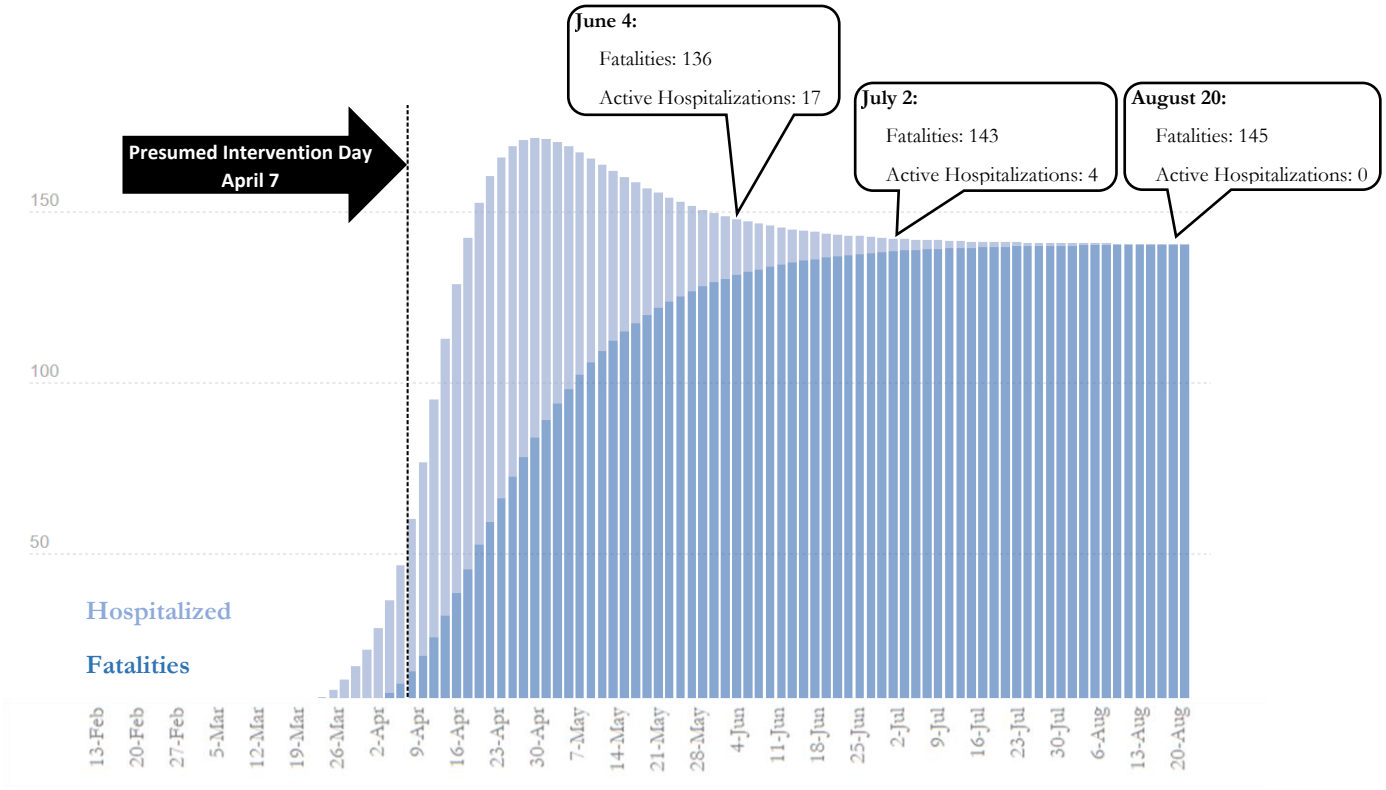


Figure 5: The patterns of active hospitalization and deaths if the presumed intervention on April 7 decreased transmission by 80% (other assumptions are presented in Table 2)



The status if we had practiced weaker social distancing practices

Figure 6: 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)

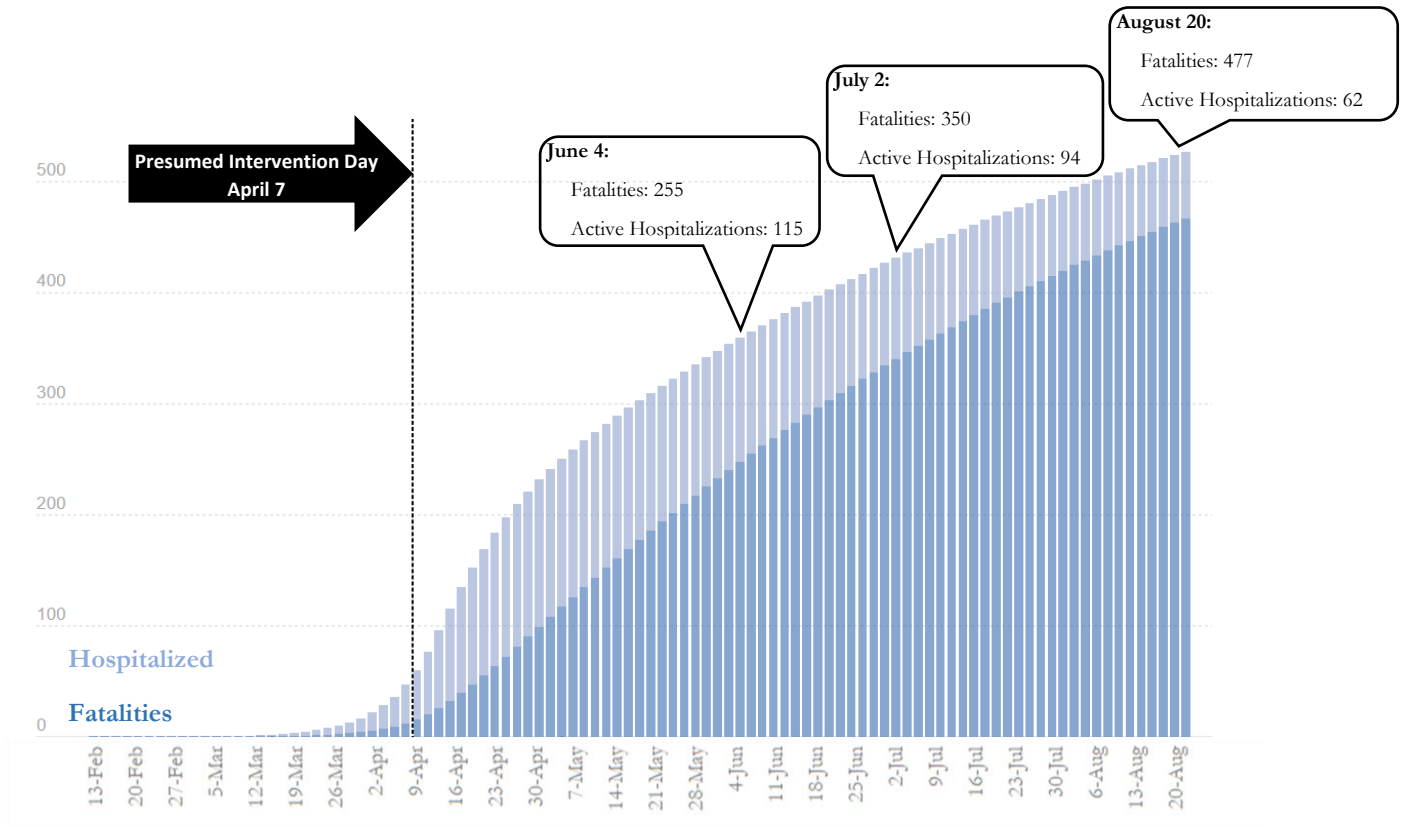


Figure 7: The patterns of active hospitalization and deaths if the presumed intervention on April 7 decreased transmission by 60% (other assumptions are presented in Table 2)

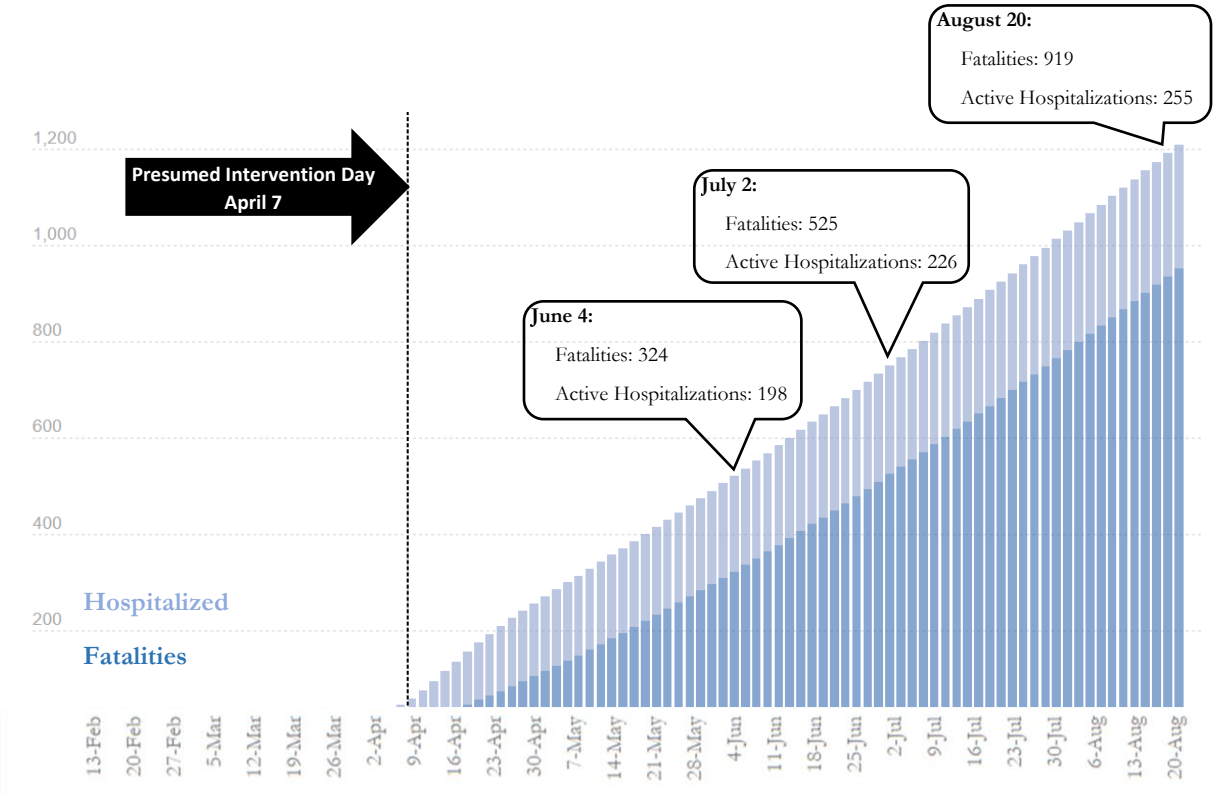


Figure 8: Projected weekly numbers of **active hospitalizations** under different social distancing scenarios (The status quo: the intervention on April 7 decreased transmission by 70%)

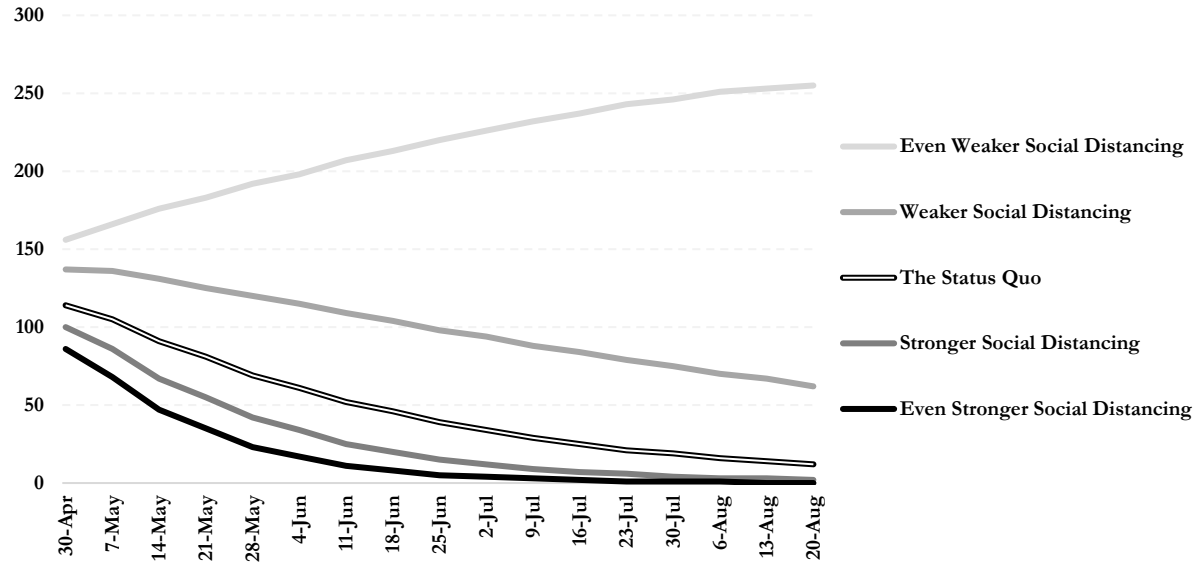


Figure 8: Projected numbers of **total fatalities** by week under different social distancing scenarios (The status quo: the intervention on April 7 decreased transmission by 70%)