# On the effects of healthcare overextension on increased mortality rate in the COVID-19 pandemic

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## COVID-19 and Intensive Care Units

One of the most visible effects of the ongoing COVID-19 pandemic is an overburden on the healthcare system. This not only limits the medical resources available to COVID-19 patients, but leads to other poor outcomes. One category of ongoing stress to healthcare systems is the availability of intensive care units (ICU) for the extremely sick.

Beyond the headline counts of ICU beds available, it is likely that an important factor in the recovery rate is that the number of patients that can receive high-quality care is below the number of beds available.

## Healthcare Overburden and COVID-19 in the Literature

Comorbidities

Healthcare overburden has been shown to lead to poor outcomes beyond the pandemic itself, such as an increase in complications related to other diseases. This is expected, as in previous epidemics the damage to the healthcare system has had a bigger toll than the epidemic itself.

ICU care

ICU care depends not only on the count of beds, but the availability of ICU staff, with increased rates of mortality among patients in strained ICUs. As regular ICU beds are filled, hospital units that typically deal with less acute patients must be repurposed as intensive care, with the associated reallocation of staff that may not have ICU training and who typically care for non-critical patients to intensive or progressive care units. The availability of ICU care may be further lowered as the providers and nurses needed to fully staff those beds are reduced as they or their family members become sick, or they have to stay home with children in remote learning.

ICU and mortality

ICU load has been shown to be positively correlated with an increase in mortality counts over the next 7 days. This increase in COVID-19 mortality is beyond a simple increase in the number of patients. ICU strain has been shown to increase the risk of mortality for patients relative to unstrained times. There was a small yet significant correlation between case fatality rate and total number of cases in the first months of the pandemic. COVID-19 mortality is also related to the overall level of infections in the community. Rapid reallocation of hospital beds and staff between provinces in Wuhan and Hubei is credited with lowering the mortality rate and raising the recovery rate.

## Our Analysis: The Excess of Fatalities due to Hospital Overburden

Research Question

The goal of this research is to construct a mathematical model which takes into consideration the health system overcapacity and determines what consequences hospital overburden produces for public health, specifically by quantifying the excess in fatalities.

An SEIHRF model

We will study the effects of healthcare system overextension by means of a compartmental model which extends the traditional SEIR model by including a mortality compartment $F$ and a hospitalization compartment $H$ in order to account for the the number of fatalities in excess due to ICU overcapacity.

## Numerical Implementations

We used a numeric ordinary differential equation solver [1] which was added to a software package (SEIRS+) that has been developed for previous research [2, 3]. Prior to adding the new model, this software package was partially refactored to simplify anticipated extensions [4].

## SEIHRF: An Extended SEIR model with Hospitalizations and Fatalities

This study incorporates hospital overcapacity and excess fatalities into an extended Susceptible-Exposed-Infectious-Recovered (SEIR) deterministic compartmental model [5, 6, 7].

First model: SEIHRF model

We have the following system of differential equations:

$$\begin{cases} N = S + E + I + H + R + F \\ \frac{dS}{dt} = -\beta \frac{SI}{N} \\ \frac{dE}{dt} = \beta \frac{SI}{N} - \sigma E \\ \frac{dI}{dt} = \sigma E - \gamma I - \mu_I I - \delta I \\ \frac{dH}{dt} = \delta I - \gamma_H H - \mu_H H \\ \frac{dR}{dt} = \gamma I + \gamma_H H \\ \frac{dF}{dt} = \mu_I + \mu_H H \end{cases} . \tag{1}$$

Here $0 \leq S, E, I, H, R, F \leq N$ correspond to susceptible, exposed, infective, hospitalized, recovered, and fatalities compartments, while $N$ represents the total population. The description of the parameters is in the table below.

| Parameter | Description |
|---|---|
| $\beta$ | Rate of transmission |
| $\sigma$ | Rate of infection |
| $\gamma$ | Rate of recovery |
| $\gamma_H$ | Rate of recovery among hospitalized infected individuals |
| $\delta$ | Rate of hospitalization of infected individuals |
| $\mu_I$ | Rate of infection-related death, excluding hospitalized individuals |
| $\mu_H$ | Rate of infection-related death among hospitalized infected individuals |
| beds | Number of well staffed hospital beds. |

Second model: SEIHRFFe model

By assuming that any patients who need hospital beds when there are none available become fatalities, fatalities in excess $F_e$ are then computed in the following way:

$$\text{excess fatalities} = \max(H + dH - \text{beds}, 0)$$

$$dH = dH - \text{excess fatalities}$$

$$dF_e = \text{excess fatalities}$$

By categorizing any hospital overcapacity as fatalities, this assumes a worst-case scenario, setting an upper limit for hospital overload related deaths. This second model leads to a slightly different compartmental model with $F$ contributed to some sort of average fatalities, and $F_e$ to the extra fatalities due to hospital overburden.

## References

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## Simulations

First model: SEIHRF model

The basic SEIR model was expanded as a SEIHRF model by adding a hospitalized infected compartment $H$ and total fatalities $F$. This model does not include any penalty term for the increase in hospital population. Each parameter in the SEIHRF model was valued by factors of $(0, 0.1, 0.5, 1)$ to examine the sensitivity to each parameter.

Second model: SEIHRFFe model

The SEIHRF model was then expanded to the SEIHRFFe to include a hard limit on hospital capacity; any cases above the capacity limit become excess fatalities ($F_e$). The hospital capacity was varied through factors of 2 up to the point where there are no excess fatalities. The variations in hospital capacity are shown in Figure 1 below. When the hospital capacity is set high enough, the SEIHRFFe model simplifies to the SEIHRF model.

## Results

As the number of fully staffed and supplied hospital beds is decreased, the excess fatalities due to hospital overburden rapidly dominates the total number of deaths in the pandemic. When the hospital capacity is saturated, the overall mortality drastically increases; $F_e$ is not only a higher fraction of the deaths, it is a significant increase in the number of deaths.

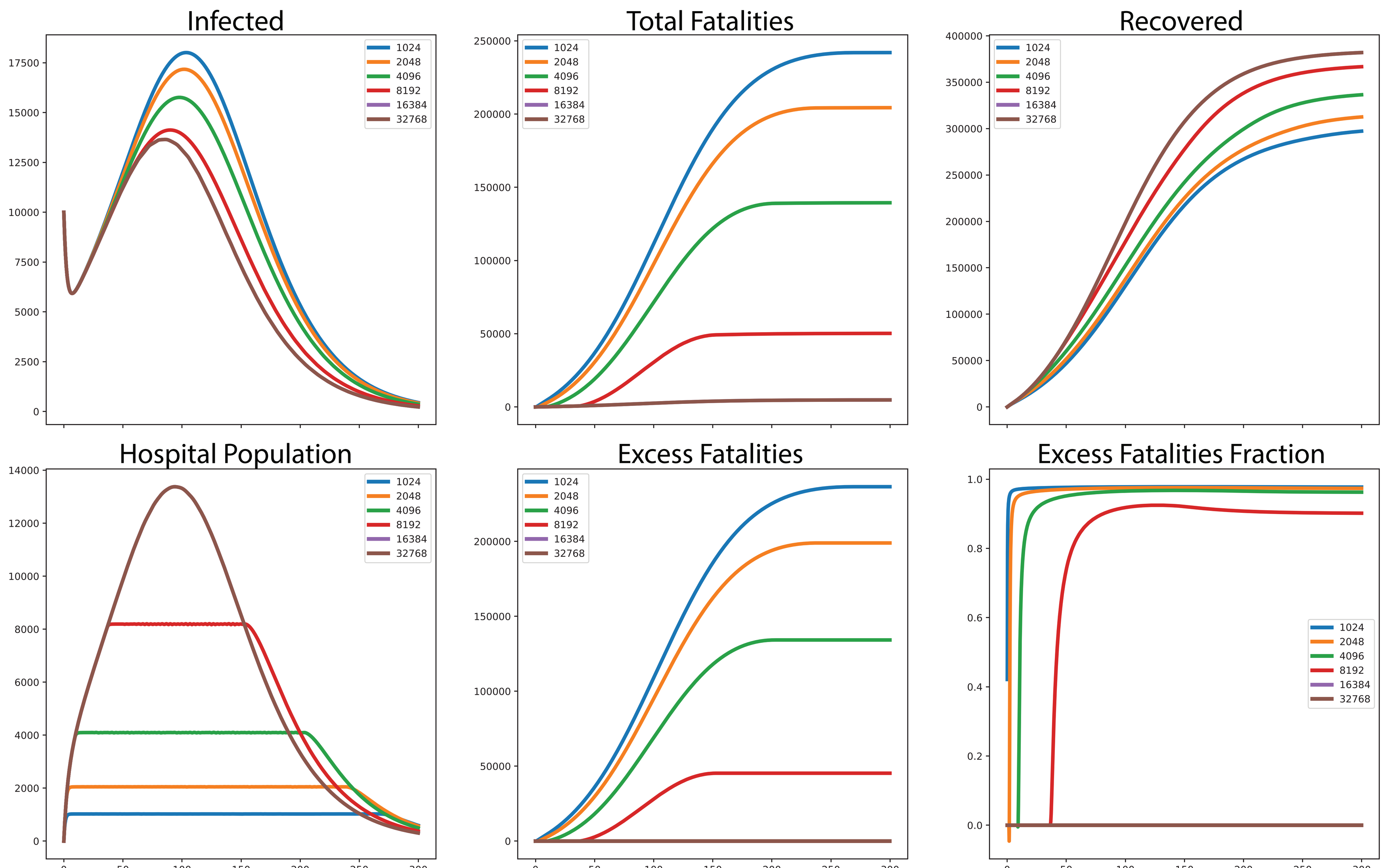


Figure 1:Evolution of the population in each compartment.

## Conclusions

We study the evolution of COVID-19 by means of a compartmental model SEIHRFFe which pays specific attention to the effect of hospitalization on the excess in fatalities.

This model shows how quickly an overextended healthcare system can result in excess in fatalities.

The rapid increase in mortality as capacity is hit confirms that impending hospital overload should be an important factor in public policy before healthcare system capacity is exceeded.