Nevada COVID-19 Model Review

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Background and Purpose

A variety of statistical models have been released at the national level to predict the near-future behavior of COVID-19. Two of these models include state-level predictions. In addition, the Department of Health and Human Services (DHHS), Office of Analytics has been working in conjunction with the University of Nevada, Reno to develop Nevada-specific models to understand the transmission and spread of COVID-19. The purpose of this brief is to consider these models, outline their strengths and weaknesses, and ultimately help guide the Governor’s Office and COVID-19 Taskforce by providing best- and worst-case scenarios.

Comparing Models and Model Results (as of April 2nd, 2020)

Institute for Health Metrics and Evaluation (IHME) Model

The IHME is an independent global health research center at the University of Washington. The IHME model assumes strong social distancing and other protective measures.¹

Currently, this model projects peak hospitalizations on April 20th and peak count of daily deaths on April 18th, with approximately 3,000 hospital beds needed and 16 deaths per day at the peak, with a total of 799 Nevada deaths to COVID-19 by August 4th. It projects that we exceed hospital capacity by 516 beds and that we exceed ICU capacity by 232 beds at the peak.¹

This is a linear model which is based largely on death rates and will naturally predict worse outcomes as we see death rates increase. We see this even in the updates between March 31st and April 2nd. Due to the lack of U.S. specific data at around the 30-day mark, it begins to default to data from other countries such as China, where the disease spread is more progressed. This means that the predictions begin to inherently assume that around the 30-day mark we will have a similar quarantine strategy to that which was implemented in Wuhan. Based upon the severe restrictions that were implemented in Wuhan, the ability to achieve comparable outcomes in Nevada is unlikely. We find this model to be oversimplistic, producing optimistic predictions which should be interpreted as a best-case scenario.

It is important to note that this model assumes bed capacity at 2,247 in Nevada. The source of this number is unclear. The COVID ACT NOW Model, which is described in more detail below, assumes a much higher bed capacity, at 5,355. The COVID ACT NOW model also assumes that approximately 30% of hospital beds will be made available in order to accommodate COVID-19 patients. This is based on evidence that suggests baseline bed capacity typically goes up during crises due to the rescheduling of elective surgeries, etc.¹ Any assumptions that the IHME model may be making around bed capacity are unclear.

COVID ACT NOW Model

CovidActNow.org was created by a team of data scientists, engineers, and designers in partnership with epidemiologists, public health officials, and political leaders to help understand how the COVID-19 pandemic will affect their region.²
The model being used by CovidActNow.org is fundamentally like an SEIR model (Susceptible, Exposed but not infectious, Infectious, and Recovered) which takes the existing understanding of the doubling rate of the disease and forecasts that, in conjunction with an element of herd immunity (or susceptibility). It takes data on hospitalizations as input and matches that against other parts of the world with more advanced disease progression to create a best fit curve. This poses limitations in interpreting the Nevada-specific estimates, due to incomparable testing practices which are driven largely by the limited availability of testing.

We believe that this model is most accurate for the near-short term (approximately 3-4 weeks) but should not be used to accurately predict the exact date of peak or final number of deaths because those projections will vary significantly from day to day as more data are available. Because of the social distancing guidelines Nevada has put in place, including the most recent stay-at-home directive on April 1st, we believe that the predictions assuming 3 months of poor compliance to the stay-at-home order represent a potentially worst-case scenario.

Nevada-specific research

Researchers from the University of Nevada, Reno have been working in conjunction with faculty at the University of Michigan to come up with models for state-specific estimates. These models, while still in the early phases of development, are utilizing similar modeling methodology to that of the COVID ACT NOW model. They are based on an SEIR-like model, which is largely dependent on an accurate estimate of $R_0$, the basic reproduction number, and $R_t$, the effective reproduction number. In other words, $R_0$ and $R_t$ can be loosely interpreted as measures of how contagious a given infectious disease is, where $R_t$ takes into account the length of time since the start of the epidemic. Due to limitations in the current data, $R_0$ and $R_t$ are hard to estimate accurately (see appendix 3: P. Hurtado, Epidemic Trajectories and Reproduction Numbers, March 31st, 2020).

Still, despite lacking concrete model results, there is agreement that future outcomes will be largely dependent on the social distancing practices that are put in place. The illustration below is a simplified representation of how measures such as social distancing and personal protective equipment (PPE) have a direct impact on the estimate of $R_t$. The decrease in the number of infected people is proportional to the decrease in person-to-person contact.
Conclusions

There are current limitations which make modeling COVID-19 difficult (see appendix 3: *P. Hurtado, Epidemic Trajectories and Reproduction Numbers, March 31st, 2020*). Estimates of the timing and size of peaks, regardless of model or source, should be used as a guide and with an understanding that these will change fluidly as we see the COVID-19 pandemic progress. The table below illustrates this fluidity, specifically in the COVID ACT NOW model, by presenting the differences in predictions from March 31st to April 2nd, 2020.

COVID ACT NOW Model, prediction comparison from March 31st to April 2nd, 2020

Results as of March 31st, 2020 (updated on March 27th)

<table>
<thead>
<tr>
<th>Social Distancing Assumptions</th>
<th>Estimated Date of Peak Hospitalizations</th>
<th>Estimated Number of Hospitalizations at Peak</th>
<th>Estimated Date of Hospital Capacity Overload</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social distancing, with recommendation to stay home</td>
<td>Limited action</td>
<td>4/28/2020</td>
<td>&gt; 65,000</td>
</tr>
<tr>
<td>3 months of social distancing</td>
<td>5/14/2020</td>
<td>&gt; 25,000</td>
<td>4/20/2020</td>
</tr>
<tr>
<td>3 months of shelter-in-place</td>
<td>5/26/2020</td>
<td>~ 1,300</td>
<td>never</td>
</tr>
</tbody>
</table>

Results as of April 2nd, 2020 (updated on April 2nd)

<table>
<thead>
<tr>
<th>Social Distancing Assumptions</th>
<th>Estimated Date of Peak Hospitalizations</th>
<th>Estimated Number of Hospitalizations at Peak</th>
<th>Estimated Date of Hospital Capacity Overload</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stay-at-home order in place</td>
<td>Limited action</td>
<td>5/11/2020</td>
<td>&gt; 50,000</td>
</tr>
<tr>
<td>3 months of poor adherence to stay-at-home order</td>
<td>6/15/2020</td>
<td>&gt; 16,000</td>
<td>5/12/2020</td>
</tr>
<tr>
<td>3 months of strict adherence to stay-at-home order</td>
<td>6/9/2020</td>
<td>~ 3,000</td>
<td>never</td>
</tr>
</tbody>
</table>

Despite these limitations, there is consensus in the directionality of the predictions and in the recommendation that future outcomes will be largely and proportionally dependent on preventative measures that are put in place (social distancing, shelter-in-place, etc.), as well as adherence to these mandates. A drastic reduction in person-to-person contact will not only assist in ‘flattening of the curve’ but will also ultimately reduce the cumulative number of cases, hospitalizations, and deaths related to COVID-19. Therefore, the continuation of strict mandates such as shelter-in-place orders are recommended in order to achieve the greatest impact on case reduction.
Appendices

1. IHME Model Output April 2nd, 2020

- Hospital resource use
- Resources needed for COVID-19 patients on peak date
- 18 days until peak resource use on April 20, 2020

- Deaths per day
- 16 days until peak count of daily deaths
- 26 COVID-19 deaths projected on April 18, 2020

- Total deaths
- 799 COVID-19 deaths projected by August 4, 2020
2. COVID ACT NOW Model Output April 2\textsuperscript{nd}, 2020

Projected hospitalizations
Nevada

- Limited action
- 3 months of Stay at home (strict compliance)
- 3 months of Lockdown

Current Intervention | Hospital Capacity
---|---
Stay at home | Poor Compliance
Legal order for citizens to employ "stay at home" quarantine except for essential activities, shutdown of non-essential businesses, ban on all group events. | We project hospitals will become overloaded by May 12.

Strict Compliance | We project no overload over the next 3 months

Predicted Outcomes after 3 Months

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Estimated Cumulative Infected</th>
<th>Estimated Date Hospitals Overloaded</th>
<th>Estimated Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limited action</td>
<td>&gt; 70%</td>
<td>Fri Apr 17 2020</td>
<td>33,000</td>
</tr>
<tr>
<td>3 Months of Stay at home (poor compliance)*</td>
<td>63%</td>
<td>Tue May 12 2020</td>
<td>14,000</td>
</tr>
<tr>
<td>3 Months of Stay at home (strict compliance)*</td>
<td>14%</td>
<td>never</td>
<td>4,000</td>
</tr>
<tr>
<td>3 Months of Lockdown**</td>
<td>2%</td>
<td>never</td>
<td>&lt; 1000</td>
</tr>
</tbody>
</table>
A second spike in disease may occur after social distancing is stopped. Interventions are important because they buy time to create surge capacity in hospitals and develop therapeutic drugs that may have potential to lower hospitalization and fatality rates from COVID. See full scenario definitions here.

Our models show that it would take at least 2 months of Wuhan-style Lockdown to achieve full containment. However, it is unclear at this time how you could manage newly introduced infections. See full scenario definitions here.

3. Epidemic Trajectories and Reproduction Numbers

Epidemic Trajectories and Reproduction Numbers
Paul Hurtado
3/31/2020

This document summarizes the role that quantities like $R_0$ (the basic reproduction number) and $R_t$ (the effective reproduction number) play in the trajectory of an epidemic, and how they relate to model parameters that describe different “real world” biological processes that make up the overall transmission and recovery process.

SEIR Model: A Simple Example

To illustrate some of these concepts, I will use a very simple transmission model known as the SEIR model (Susceptible, Exposed but not Infectious, Infectious, and Recovered). More elaborate versions of this model are what many are using for forecasting SARS-COV-2/COVID-19 epidemics.

$$\frac{dS}{dt} = -cp IS$$
$$\frac{dE}{dt} = cp SI - r_E E$$
$$\frac{dI}{dt} = r_E E - r_I I$$
$$\frac{dR}{dt} = r_I I$$

Here $cpS I$ is the Transmission Rate (individuals per unit time), where the product $cpS$ gives the average number of contacts between an infected individual and susceptible individuals, and $p$ is the proportion of those contacts that is expected to yield new infections. $r_E$ is the rate of exposed individuals becoming infectious (equivalently, $1/r_E$ is the mean time between exposure and becoming infectious), and $r_I$ is the rate of infected individuals recovering (equivalently, $1/r_I$ is the mean duration of infectiousness).

Basic Reproduction Number

The basic reproduction number $R_0$ is interpreted as follows: the expected number of new infections created on average by a single infectious individual in a purely susceptible population. For this model, $R_0$, depends on the parameters above as follows:

$$R_0 = \frac{cpS_0}{r_I} = \frac{Rate \ of \ new \ Inf.}{Mean \ Inf. \ Period}$$

The numeric value of $R_0$ can be used as follows.

Introducing a single individual to a fully susceptible population (of size $S_0$) under this model will yield one of two outcomes: either infections will increase and an epidemic will occur (if $R_0 > 1$), or infections will decrease and no epidemic will occur ($R_0 < 1$). Additionally, if we think of time in units of mean infectious period, then $R_0$ tells us the initial exponential growth rate of the cumulative infection curve.
Effective Reproduction Number

A second useful quantity is the effective reproduction number $\mathcal{R}_e$, which is analogous to the basic reproduction number $R_0$ but gives the expected number of new infections per infectious individual after a time duration of length $t$ since the start of the epidemic:

$$\mathcal{R}_e = c_p S(t) \frac{1}{\tau_I} = R_0 \frac{S(t)}{S(0)}$$

$\mathcal{R}_e$ decreases from an initial value $R_0$ by the proportion of susceptibles remaining in the population at time $t$. It can also drop if parameter values change over time (e.g., social distancing measures would decrease $c$).

Notice that, if we sum $E(t)$ and $I(t)$ to get the total number of infected at time $t$, $x(t) = E(t) + I(t)$, and if we rescale time units to be the mean infectious period by using the scaled time variable $\tau = \frac{t}{\gamma}$ then the equation for how $x$ increases and decreases over time is given by

$$\frac{dx}{d\tau} = \frac{1}{\gamma} \left( \frac{dE}{dt} + \frac{dI}{dt} \right)$$

$$= \left( \frac{c_p S}{\gamma} - 1 \right) I$$

$$= (\mathcal{R}_e - 1) I$$

Thus, as the epidemic progresses, if the effective reproduction number drops below 1, then the number of new cases will have a negative derivative, and therefore be decreasing. This typically coincides (in simple models like this one) with the point at which the number of recovered (immune) individuals in the population is sufficiently high so that the susceptible portion of the population ($S(t)$) drops sufficiently low.

Measures taken to control an epidemic can be thought of in terms of how they influence the different component parts of this quantity $\mathcal{R}_e$.

$$\frac{dx}{d\tau} = \left( \frac{c_p S}{\gamma} - 1 \right) I$$

Changes in parameters over time (like decreasing $c_p$ through social distancing, wearing masks, washing hands, etc.) can also decrease $\mathcal{R}_e$, or increase it (e.g., removing shelter in place orders).

Summary Remarks Pertaining to COVID-19

1. Currently, the data suggest we are in the exponential growth phase of the epidemic (log-scale plots of Cumulative Case Counts look linear, and aren’t tapering off). This allows us to estimate $R_0$, but greatly limits our ability to know the size and timing of the peak. Even with perfect data, there would be much uncertainty associated with estimates of the size and timing of the peak.

2. Compounding this limitation, we have experienced variable and biased testing rates (e.g., there is strong bias towards only testing more severe cases, and testing was very limited early on). This further impedes our ability to estimate parameters, including $R_0$. As testing capacity increases, and we don’t have a backlog of tests coming out, this might lead to an apparent slowing in the exponential growth rate that could lead many models to make biased predictions about the peak (they could underestimate the time to, and size of, the peak). Updated time series data, e.g., dates for the onset of symptoms associated with positive tests, could help correct this issue with the testing data. Hospitalizations and deaths are expected to be less biased data, but lag behind the testing data.

3. Despite the limitations of various crude modelling results available for other states and online, the qualitative comparisons made using some of these models are worthy of consideration. Social distancing, prohibiting large gatherings, and other measures are very likely to slow spread, reduce peak case sizes, and thereby help mitigate the risk of hospitals exceeding capacity. Estimates of the timing and size of the peak are much more uncertain, and should be interpreted with extreme caution.

References
