Abstract

We propose a novel model based on a set of coupled delay differential equations with fourteen delays in order to accurately estimate the incubation period of COVID-19, employing publicly available data of confirmed corona cases. The optimal values of the model parameters are obtained by minimizing the error function. In this goal, we separate the total cases into fourteen groups for the corresponding fourteen incubation periods. The estimated mean incubation period we obtain is 6.74 days (95% Confidence Interval(CI): 6.35 to 7.13), and the 90th percentile is 11.64 days (95% CI: 11.22 to 12.17), corresponding to a good agreement with statistical supported studies.

Results

Fig. 1: Probability density function of the lognormal distribution of the incubation period with $\mu = 1.79$ and $\sigma = 0.52$. The result based on the total confirmed corona cases of 276 days. The bars indicate the densities obtained from the model.

Table 1: Sample size, mean and lognormal parameters $\mu$, $\sigma$. R denotes the calculated results using proposed model.

<table>
<thead>
<tr>
<th>Author</th>
<th>Data size</th>
<th>Mean (days)</th>
<th>$\mu$</th>
<th>$\sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lauer et al.</td>
<td>181</td>
<td>5.5</td>
<td>1.621</td>
<td>0.418</td>
</tr>
<tr>
<td>Bi et al.</td>
<td>183</td>
<td>4.8</td>
<td>1.570</td>
<td>0.650</td>
</tr>
<tr>
<td>Linton et al.</td>
<td>158</td>
<td>5.6</td>
<td>1.611</td>
<td>0.472</td>
</tr>
<tr>
<td>Ma et al.</td>
<td>587</td>
<td>7.4</td>
<td>1.857</td>
<td>0.547</td>
</tr>
<tr>
<td>McAloon et al.</td>
<td>Meta</td>
<td>5.8</td>
<td>1.63</td>
<td>0.50</td>
</tr>
<tr>
<td>Jing et al.</td>
<td>1084</td>
<td>8.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R (data)</td>
<td>211,735</td>
<td>6.89</td>
<td>1.788</td>
<td>0.520</td>
</tr>
<tr>
<td>R (lognormal)</td>
<td>211,735</td>
<td>6.7</td>
<td>1.788</td>
<td>0.520</td>
</tr>
<tr>
<td>R (data)</td>
<td>2,587</td>
<td>7.17</td>
<td>1.827</td>
<td>0.528</td>
</tr>
<tr>
<td>R (lognormal)</td>
<td>2,587</td>
<td>7.0</td>
<td>1.827</td>
<td>0.528</td>
</tr>
</tbody>
</table>

Method

Fig. 2: Schematic diagram of the compartmental based epidemic model, presented in Equation 1.

The model is the following set of coupled delay differential equations:

$$
\begin{align*}
\frac{dS}{dt} &= -\beta(t) S I / N - \alpha(t) S + \nu(t) L, \\
\frac{dI}{dt} &= \beta(t) N - \sum_{i=1}^{J} \delta_i(t) \beta(t) S(t - \tau_i) I(t - \tau_i) / N, \\
\frac{dT_i}{dt} &= \delta_i(t) \beta(t) S(t - \tau_i) I(t - \tau_i) / N, \\
\frac{dL}{dt} &= \alpha(t) S - \nu(t) L,
\end{align*}
$$

(1)

The optimal values of $p(t) = (q, \alpha(t), \beta(t), \delta_1(t), \ldots, \delta_J(t), \nu)^T$, that is the set of initial value and model parameters, is obtained by minimizing the error function $E(p(t))$, defined as

$$
E(p(t)) = \frac{1}{M} \sum_{k=1}^{M} (T^{(k)}(p(t)) - \tilde{T}^{(k)})^2,
$$

(2)

where $\tilde{T}^{(k)}$ is the available data of total corona-positive cases on the particular $k$th day, and $T^{(k)}$ is the calculated results obtained from System (1). We consider a calculation of 276 days, from January 22, 2020 to October 23, 2020. We decompose the time domain of 276 days into two parts : the time domain splitter is in the interval where the “first wave” is slowed down and the “second wave” begins.

$$
\begin{align*}
p(t) &= p^{(1)} \text{ from January 22, 2020 to July 19, 2020}, \\
p(t) &= p^{(2)} \text{ from July 20, 2020 to October 23, 2020}.
\end{align*}
$$

(3)

Reference

Paul and Lorin, Distribution of Incubation Period of COVID-19 in the Canadian Context: Modeling and Computational Study (medRxiv) doi: https://doi.org/10.1101/2020.11.20.20235648