

Appendix: Covid-19 model specification

25 March 2020

(Minor revisions made 30 March 2020)

Model overview

The model is an ordinary differential equation model based on the standard SEIR (susceptible-exposed-infected-removed) approach. This is very similar to the CovidSIM model, parameterised by Wilson et al (2020) for Covid19 spread in the NZ population. The model compartments are shown below:

The model variables are the following fractions of the total population:

- Susceptible (S). Individuals who have not been infected.
- Exposed (E). Individuals who have been infected with the virus but are not yet infectious.
- Presymptomatic (P). Individuals who are infectious but not yet symptomatic.
- Infectious, untested (I_u). Symptomatic infections that have not been tested (unconfirmed cases).
- Infectious, tested (I_t). Symptomatic infections that have been tested (confirmed cases).
- Recovered, untested (R_u). Recovered individuals that were not tested.
- Recovered, tested (R_t). Recovered individuals that were tested.
- Deaths (D).

Once an individual is exposed, they follow a pathway through the compartments as shown in the diagram and end up in either the R_u , R_t or D compartment. Model parameters were derived based on the following assumptions:

- We ran simulations of the model with basic reproduction number $R_0 = 2.5$ (although as there is uncertainty about the value of R_0 we also tested $R_0 = 1.5$ and $R_0 = 3.5$).
- The mean time spent in each compartment were as follows: Exposed 4 days (latent period); Presymptomatic 1 day; Symptomatic infectious 10 days (Wilson et al 2020).

- Infectiousness in the presymptomatic period is 15% of the infectiousness in the symptomatic period (Wilson et al 2020).
- The number of infections requiring hospitalisation was assumed to be 5% of all infections, and the number requiring ICU was 1.25% of all infections.
- A baseline infection fatality ratio (IFR) of 1%. This is the proportion of all infections that result in death. This IFR was applied at times when the number of cases requiring ICU was below maximum capacity, assumed to be 500 ICU beds.
- When the number of cases requiring ICU was above capacity, an increased IFR of 2% was applied to infections exceeding the ICU capacity.
- Testing of symptomatic infections occurs at a fixed rate c . For the baseline case, we set c to a value that resulted in an average time between becoming symptomatic and being tested of 10 days.
- The simulations were initialised with a fixed number of exposed individuals (20) and it was assumed there were no subsequent imported infections.
- The total population size was assumed to be fixed, i.e. no immigration/emmigration, births or deaths from causes other than Covid19 over the time period simulated.
- The effect of control measures aimed at reducing transmission was tested by reducing the transmission coefficient β by a set amount either: (i) during fixed time intervals; or (ii) triggered by an intervention rule, such as reaching a pre-defined number of confirmed cases or ICU load.

See below for complete set of model equations and parameter values).

Model equations and parameter values

Model equations reflecting the transition routes shown in the diagram are:

$$\frac{dS}{dt} = -\beta S (\epsilon P + I_u + I_t) \quad (1)$$

$$\frac{dE}{dt} = \beta S (\epsilon P + I_u + I_t) - \alpha E \quad (2)$$

$$\frac{dP}{dt} = \alpha E - \delta P \quad (3)$$

$$\frac{dI_u}{dt} = \delta P - (\gamma + c)I_u \quad (4)$$

$$\frac{dI_t}{dt} = cI_u - \gamma I_t \quad (5)$$

$$\frac{dR_u}{dt} = \gamma(1 - IFR)I_u \quad (6)$$

$$\frac{dR_t}{dt} = \gamma(1 - IFR)I_t \quad (7)$$

$$D = 1 - S - E - P - I_u - I_t - R_u - R_t \quad (8)$$

$$IFR = \begin{cases} IFR_0 & \text{if } NI_{pICU} \leq n_{ICU}, \\ IFR_1 - \frac{n_{ICU}}{NI_{pICU}}(IFR_1 - IFR_0) & \text{otherwise} \end{cases} \quad (9)$$

The model was initialised with 20 exposed individuals ($E(0) = 20/N$ where N is population size), representing arrivals from overseas. Although the initial condition affects the timing of the peak it does not substantially alter any other model outputs.

Parameters values are shown in the table below:

Parameter	Value	
Basic reproduction number	$R_0 = 2.5$	
Total population size	$N = 5$ million	
$E \rightarrow P$ transition rate	$\alpha = 0.25 \text{ day}^{-1}$	Wilson et al (2020)
$P \rightarrow I$ transition rate	$\delta = 1 \text{ day}^{-1}$	Wilson et al (2020)
$I \rightarrow R$ transition rate	$\gamma = 0.1 \text{ day}^{-1}$	Wilson et al (2020)
Relative infectiousness in presymptomatic period	$\epsilon = 0.15$	Wilson et al (2020)
Transmission coefficient	$\beta = \frac{R_0}{\epsilon/\delta+1/\gamma} = 0.2463 \text{ day}^{-1}$	
Testing rate for symptomatic infections	$c = 0.1 \text{ day}^{-1}$	
Infection fatality rate (when ICU is under max. capacity)	$IFR_0 = 1\%$	
Infection fatality rate (for infections exceeding ICU capacity)	$IFR_1 = 2\%$	
Proportion of total infections requiring hospitalisation	$p_{\text{hosp}} = 5\%$	Wilson et al (2020)
Proportion of total infections requiring ICU	$p_{ICU} = 1.25\%$	Wilson et al (2020)
Estimated ICU maximum capacity	$n_{ICU} = 500$ beds	Ministry of Health (2005)