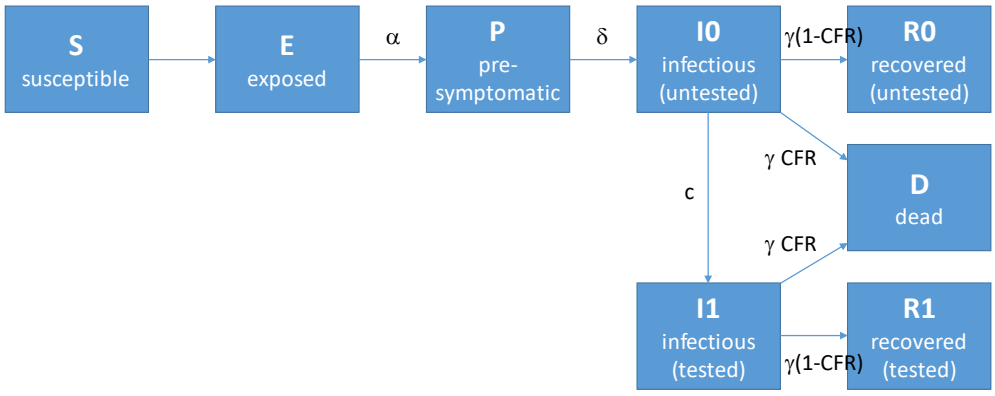
Epidemic model for Covid-19

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:

- 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_0). Symptomatic cases that have not been tested (unconfirmed cases).
- Infectious, tested (I_1). Symptomatic cases that have been tested (confirmed cases).

- Recovered, untested (R_0). Recovered cases that were not tested.
- Recovered, tested (R_1). Recovered cases 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_0, R_1 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 cases requiring hospitalisation was assumed to be 5% of all cases, and the number requiring ICU was 1.25% of all cases.
- A baseline case fatality ratio (CFR) of 1%. This is the proportion of all cases that result in death, also known as the infection fatality ratio. This CFR was applied at times when the number of cases requiring ICU was below maximum capacity, assumed to be 800 ICU beds.
- When the number of cases requiring ICU was above capacity, an increased CFR of 2% was applied to cases exceeding the ICU capacity.
- Testing of symptomatic cases occurs at a fixed rate c. For the baseline case, we set c to a value that resulted in an average time between becoming sympotomatic and being tested of 10 days. The effect of varying this parameter will be investigated.
- The simulations were initialised with a fixed number of cases (20) and it was assumed there were no subsequent imported cases.
- 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:

$$\frac{dS}{dt} = -\beta S\left(\epsilon P + I_0 + I_1\right) \quad (1)$$

$$\frac{dE}{dt} = \beta S\left(\epsilon P + I_0 + I_1\right) - \alpha E \quad (2)$$

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

$$\frac{dI_0}{dt} = \delta P - (\gamma + c) I_0 \quad (4)$$

$$\frac{dI_1}{dt} = c I_0 - \gamma I_1 \quad (5)$$

$$\frac{dR_0}{dt} = \gamma(1 - CFR) I_0 \quad (6)$$

$$\frac{dR_1}{dt} = \gamma(1 - CFR) I_1 \quad (7)$$

$$D = 1 - S - E - P - I_0 - I_1 - R_0 - R_1 \quad (8)$$

$$CFR = CFR_1 - \frac{n_{\text{ICU}}}{N I p_{\text{ICU}}}(CFR_1 - CFR_0) \quad (9)$$

The model was initialised with 20 exposed cases ($E(0) = 20/N$ where N is population size), representing arrivals from overseas. Although the initial case number 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	
$E \to P$ transition rate	$\alpha = 0.25$ day^{-1}	Wilson et al (2020)
$P \to I$ transition rate	$\delta = 1$ day^{-1}	Wilson et al (2020)
$I \to R$ transition rate	$\gamma = 0.1$ day^{-1}	Wilson et al (2020)
Relative infectiousness in presymptomatic period	$\epsilon = 0.15$	Wilson et al (2020)
Transmission coefficient	$\beta = \frac{R_0}{\epsilon/\delta + 1/\gamma} = 0.2463$ day^{-1}	
Testing rate for symptomatic cases	$c = 0.1$ day^{-1}	
Case fatality rate (when ICU is under max. capacity)	$CFR_0 = 1\%$	
Case fatality rate (for cases exceeding ICU capacity)	$CFR_1 = 2\%$	
Proportion of total cases requiring hospitalistion	$p_{\text{hosp}} = 5\%$	Wilson et al (2020)
Proportion of total cases requiring ICU	$p_{\text{ICU}} = 1.25\%$	Wilson et al (2020)
ICU maximum capacity	$n_{\text{ICU}} = 300$ beds	Ministry of Health (2005)

Notes

1. A previous version of the model neglected the presymptomatic stage. This is equivalent to setting $1/\delta = 0$ so that individuals do not remain in the presymptomatic stage for any length of time. This makes a small different to model results.

References

1. Ministry of Health (2005). Intensive Care Services in New Zealand: A report to the Deputy Director-General, Clinical Services. Wellington: Ministry of Health.

2. Wilson N et al (13 March 2020). Modelling of the Potential Health Impact from the COVID-19 Pandemic on the New Zealand Population Using the CovidSIM Model: Report to the NZ Ministry of Health.