

SARS-CoV-2 transmission model

Code ▼

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The model simulates the time course of the state variables defined by the following set of differential equations:

$$\begin{aligned}
 dS_1/dt &= -\lambda_1 \cdot S_1 \\
 dE_1/dt &= \lambda_1 \cdot S_1 - E_1/\delta_E \\
 dI_1/dt &= E_1/\delta_E - I_1/\delta_I \\
 dH_1/dt &= \phi_{H1} \cdot I_1/\delta_I - \phi_{C1} \cdot H_1/(0.75 \cdot \delta_H) - (1 - \phi_{C1}) \cdot H_1/\delta_H \\
 dC_1/dt &= \phi_{C1} \cdot H_1/(0.75 \cdot \delta_H) - C_1/\delta_C \\
 dR_1/dt &= (1 - \phi_{H1}) \cdot I_1/\delta_I + (1 - \phi_{C1}) \cdot H_1/\delta_H + (1 - \mu_1) \cdot C_1/\delta_C \\
 dD_1/dt &= \mu_1 \cdot C_1/\delta_C \\
 dS_2/dt &= -\lambda_2 \cdot S_2 \\
 dE_2/dt &= \lambda_2 \cdot S_2 - E_2/\delta_E \\
 dI_2/dt &= E_2/\delta_E - I_2/\delta_I \\
 dH_2/dt &= \phi_{H2} \cdot I_2/\delta_I - \phi_{C2} \cdot H_2/(0.75 \cdot \delta_H) - (1 - \phi_{C2}) \cdot H_2/\delta_H \\
 dC_2/dt &= \phi_{C2} \cdot H_2/(0.75 \cdot \delta_H) - C_2/\delta_C \\
 dR_2/dt &= (1 - \phi_{H2}) \cdot I_2/\delta_I + (1 - \phi_{C2}) \cdot H_2/\delta_H + (1 - \mu_2) \cdot C_2/\delta_C \\
 dD_2/dt &= \mu_2 \cdot C_2/\delta_C
 \end{aligned}$$

with state variables:

S : susceptible

E : exposed (i.e. during the incubation time)

I : infectious

H : in hospital

C : in ICU

R : recovered

D : dead

$N = S + E + I + R$

The subscript 1 or 2 (for instance S_1) indicates the age group.

Age group 1 : < 50 years

Age group 2: from 50 years

$\lambda_1 = \beta_1 \cdot \{w \cdot I_1/N_1 + (1 - w) \cdot I_2/N_2\}$

$\lambda_2 = \{\beta_2 - \beta_1 \cdot (1 - w) \cdot N_1/N_2\} \cdot I_2/N_2 + (1 - w) \cdot \beta_1 \cdot N_1/N_2 \cdot I_1/N_1$

δ_E : duration of incubation period

δ_I : duration of infectious period

δ_H : duration in hospital (excluding duration in ICU)

δ_C : duration in ICU

ϕ_H : fraction needing hospitalization

ϕ_C : fraction hospitalized needing care in ICU

μ : fraction in ICU not surviving

Parameter values:

$$\delta_E = 4.6 \text{ days}$$

$$\delta_I = 4.6 \text{ days}$$

$$\delta_H = 8 \text{ days}$$

$$\delta_C = 10 \text{ days}$$

$$\phi_{H1} = 0.0203$$

$$\phi_{C1} = 0.05674$$

$$\phi_{H2} = 0.1688$$

$$\phi_{C2} = 0.355$$

Baseline parameters (not simulated):

$$\beta_1 = 0.617/day \text{ (contacts per person per day)}$$

$$\beta_2 = 0.380/day \text{ (contacts per person per day)}$$

$$w = 0.863$$

Parameters during intervention ($0 < t < 300$ days):

$$\beta_1 = 0.303/day \text{ (contacts per person per day)}$$

$$\beta_2 = 0.160/day \text{ (contacts per person per day)}$$

$$w = 0.97$$

Parameters after intervention ($t \geq 300$ days):

$$\beta_1 = 0.432/day \text{ (contacts per person per day)}$$

$$\beta_2 = 0.186/day \text{ (contacts per person per day)}$$

$$w = 0.863$$

Initial conditions:

$$S_1(0) = 10000 - E_1(0) - I_1(0)$$

$$E_1(0) = 3.75$$

$$I_1(0) = 3.75$$

$$H_1(0) = 0$$

$$C_1(0) = 0$$

$$R_1(0) = 0$$

$$D_1(0) = 0$$

$$S_2(0) = 7000 - E_2(0) - I_2(0) - H_2(0) - C_2(0)$$

$$E_2(0) = 1.25$$

$$I_2(0) = 1.25$$

$$H_2(0) = 0.3$$

$$C_2(0) = 0.2$$

$$R_2(0) = 0$$

$$D_2(0) = 0$$

The time course of the state variables is simulated over a period of 700 days using the Adams integration method of the ode function in the deSolve R package (Karline Soetaert et al.)

The baseline values of parameters β_1 and β_2 were calculated from aggregated contact rates for age groups younger than 50 years and older than 50 years, respectively [2] and an R_0 of 2.4 [1]. Data for the population composition was downloaded from CBS Statline (opendata.cbs.nl).

Other parameter values were based on [1].

1. Neil M. Ferguson et al. Impact of non-pharmaceutical interventions (NPIs) to reduce COVID19 mortality and healthcare demand. Imperial College COVID-19 Response Team, 16 maart 2020.
<https://doi.org/10.25561/77482> (<https://doi.org/10.25561/77482>)
2. Mossong J, Hens N, Jit M, Beutels P, Auranen K, Mikolajczyk R, et al. (2008) Social Contacts and Mixing Patterns Relevant to the Spread of Infectious Diseases. PLoS Med 5(3): e74.
<https://doi.org/10.1371/journal.pmed.0050074> (<https://doi.org/10.1371/journal.pmed.0050074>)