SARS-Cov2 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:

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\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

$$
\begin{aligned}
\lambda_1 &= \beta_1 \cdot \{w \cdot I_1/N_1 + (1-w) \cdot I_2/N_2\} \\
\lambda_2 &= \{\beta_2 - \beta_1 \cdot (1-w) \cdot N_1/N_2\} \cdot I_2/N_2 + (1-w) \cdot \beta_1 \cdot N_1/N_2 \cdot I_1/N_1
\end{aligned}
$$

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:
$\delta_E = 4.6$ days
$\delta_I = 4.6$ days
$\delta_H = 8$ days
$\delta_C = 10$ days
$\phi_{H1} = 0.0203$
$\phi_{C1} = 0.05674$
$\phi_{H2} = 0.1688$
$\phi_{C2} = 0.355$

Baseline parameters (not simulated):
$\beta_1 = 0.617/day$ (potentially infectious contacts per person per day)
$\beta_2 = 0.380/day$ (potentially infectious contacts per person per day)
$w = 0.863$

Parameters during intervention (0 < t < 300 days):
$\beta_1 = 0.303/day$ (potentially infectious contacts per person per day)
$\beta_2 = 0.160/day$ (potentially infectious contacts per person per day)
$w = 0.97$

Parameters after intervention (t >= 300 days):
$\beta_1 = 0.432/day$ (potentially infectious contacts per person per day)
$\beta_2 = 0.186/day$ (potentially infectious 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.)

Parameter values were based on:
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)