Supplemental Material

A scenario modelling analysis to anticipate the impact of COVID-19 vaccination in adolescents and children on disease outcomes in the Netherlands, summer 2021

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Methods

We developed a deterministic age-structured compartmental susceptible-exposed-infectious-recovered (SEIR) model extended to include states for severe disease outcomes and vaccination status. The population is partitioned into 10-year age groups (0-9, 10-19, ..., 70-79, 80+). Within each age group we further partition the population into those who are unvaccinated, and separately for those who are vaccinated with 1 to 5 doses, and then finally into disease states: susceptible (S), infected but not yet infectious (E), infectious (I), hospitalized (H), in intensive care (IC), return to the hospital ward after intensive care (HIC), recovered (R), and dead (D) (Figure S1).

When a person is vaccinated, they first enter a hold state where they are vaccinated, but not yet (fully) protected. After a delay period, they enter the vaccinated and protected state for the dose they have received. We assume only susceptible individuals are vaccinated. We use the model to determine the number of daily cases, hospital admissions, and IC admissions under different vaccination scenarios. The mathematical equations for determining each outcome and the differential model equations are shown below. In the model equations, bold capital letters refer to matrices, bold lower case letters indicate vectors, and plain text lower case letters indicate scalars. Since model compartments are denoted with capital letters, but are vectors due to the age-stratification of the model, we denote them with a half arrow above the compartment symbol, e.g., $\vec{S}$. Parameter definitions and values are shown in Table S3 and Table S4.

Model Equations

$$\lambda = \beta C N^\omega (-1) (I + \sum_i I_{Vd})$$

\[
\begin{align*}
\frac{d\vec{S}}{dt} &= -\lambda \vec{S} - \alpha_1 \vec{S} + 4\omega R^3 \\
\frac{d\vec{S}_{hold,1}}{dt} &= \alpha_1 \vec{S} - \frac{1}{\delta_1} \vec{S}_{hold,1} - \lambda \vec{S}_{hold,1} \\
\frac{d\vec{S}_{v1,1}}{dt} &= \frac{1}{\delta_1} \vec{S}_{hold,1} - \eta_1 \lambda \vec{S}_{v1,1} - \alpha_2 \vec{S}_{v1,1} + 4\omega R^3 \\
\frac{d\vec{S}_{hold,2}}{dt} &= \alpha_2 \vec{S}_{v1,1} - \frac{1}{\delta_2} \vec{S}_{hold,2} - \eta_1 \lambda \vec{S}_{hold,2} \\
\frac{d\vec{S}_{v2,1}}{dt} &= \frac{1}{\delta_2} \vec{S}_{hold,2} - \eta_2 \lambda \vec{S}_{v2,1} - \alpha_3 \vec{S}_{v2,1} + 4\omega R^3 \\
\frac{d\vec{S}_{hold,3}}{dt} &= \alpha_3 \vec{S}_{v2,1} - \frac{1}{\delta_3} \vec{S}_{hold,3} - \eta_2 \lambda \vec{S}_{hold,3} \\
\frac{d\vec{S}_{v3,1}}{dt} &= \frac{1}{\delta_3} \vec{S}_{hold,3} - \eta_3 \lambda \vec{S}_{v3,1} - \alpha_4 \vec{S}_{v3,1} + 4\omega R^3 \\
\frac{d\vec{S}_{hold,4}}{dt} &= \alpha_4 \vec{S}_{v3,1} - \frac{1}{\delta_4} \vec{S}_{hold,4} - \eta_3 \lambda \vec{S}_{hold,4}
\end{align*}
\]
\[
\frac{d\hat{S}_{vd}}{dt} = \frac{1}{\delta_4} \hat{S}_{\text{hold,td}} - \eta_4 \lambda \hat{S}_{vd} - \alpha_5 \hat{S}_{vd} + 4 \omega R_{vd}^3
\]
\[
\frac{d\hat{S}_{\text{hold,td}}}{dt} = \alpha_5 \hat{S}_{vd} - \frac{1}{\delta_4} \hat{S}_{\text{hold,td}} - \eta_4 \lambda \hat{S}_{\text{hold,td}}
\]
\[
\frac{d\hat{S}_{vd}}{dt} = \frac{1}{\delta_5} \hat{S}_{\text{hold,td}} - \eta_5 \lambda \hat{S}_{vd} + 4 \omega R_{vd}^3
\]
\[
\frac{d\hat{E}}{dt} = \lambda (\hat{S} + \hat{S}_{\text{hold,td}}) - \sigma \hat{E} + \epsilon
\]
\[
\frac{d\hat{E}_{vd}}{dt} = \eta_2 (\hat{S}_{vd} + \hat{S}_{\text{hold,td}}) - \sigma \hat{E}_{vd}
\]
\[
\frac{d\hat{E}_{\text{hold,td}}}{dt} = \eta_2 (\hat{S}_{\text{hold,td}} + \hat{S}_{\text{hold,td}}) - \sigma \hat{E}_{\text{hold,td}}
\]
\[
\frac{d\hat{E}_{vd}}{dt} = \eta_2 (\hat{S}_{vd} + \hat{S}_{\text{hold,td}}) - \sigma \hat{E}_{vd}
\]
\[
\frac{d\hat{E}_{\text{hold,td}}}{dt} = \eta_2 (\hat{S}_{\text{hold,td}} + \hat{S}_{\text{hold,td}}) - \sigma \hat{E}_{\text{hold,td}}
\]
\[
\frac{d\hat{E}_{vd}}{dt} = \eta_2 (\hat{S}_{vd} + \hat{S}_{\text{hold,td}}) - \sigma \hat{E}_{vd}
\]
\[
\frac{d\hat{I}_v}{dt} = \sigma \hat{E} - (\gamma + h) \hat{I}_v
\]
\[
\frac{d\hat{I}_{vd}}{dt} = \sigma \hat{E}_{vd} - (\gamma + \eta_{\text{hosp,p}} h) \hat{I}_{vd}
\]
\[
\frac{d\hat{H}}{dt} = h \hat{I} - (i_1 + d + r) \hat{H}
\]
\[
\frac{d\hat{H}_{vd}}{dt} = \eta_{\text{hosp,p}} \hat{H}_{vd} - (i_1 + d + r) \hat{H}_{vd}
\]
\[
\frac{d\hat{H}_{vd}}{dt} = \eta_{\text{hosp,p}} \hat{H}_{vd} - (i_1 + d + r) \hat{H}_{vd}
\]
\[
\frac{d\hat{H}_{vd}}{dt} = \eta_{\text{hosp,p}} \hat{H}_{vd} - (i_1 + d + r) \hat{H}_{vd}
\]
\[
\frac{d\hat{H}_{vd}}{dt} = \eta_{\text{hosp,p}} \hat{H}_{vd} - (i_1 + d + r) \hat{H}_{vd}
\]
\[
\frac{d\hat{I}_c}{dt} = i_4 \hat{H} - (i_2 + d_{IC}) \hat{I}_c
\]
\[
\frac{d\hat{I}_{vd}}{dt} = i_4 \hat{H}_{vd} - (i_2 + d_{IC}) \hat{I}_{vd}
\]
\[
\frac{d\hat{I}_{vd}}{dt} = i_4 \hat{H}_{vd} - (i_2 + d_{IC}) \hat{I}_{vd}
\]
\[
\frac{d\hat{I}_{vd}}{dt} = i_4 \hat{H}_{vd} - (i_2 + d_{IC}) \hat{I}_{vd}
\]
\[
\frac{d\hat{I}_{vd}}{dt} = i_4 \hat{H}_{vd} - (i_2 + d_{IC}) \hat{I}_{vd}
\]
\[
\frac{d\hat{I}_{vd}}{dt} = i_4 \hat{H}_{vd} - (i_2 + d_{IC}) \hat{I}_{vd}
\]
\[
\frac{d\vec{H}_{1C}}{dt} = i_{2} \vec{C} - (d_{H_{1C}} + r_{I_{1C}})\vec{H}_{1C}
\]
\[
\frac{d\vec{H}_{IC_{1ad}}}{dt} = i_{2} \vec{C}_{1ad} - (d_{H_{IC_{1ad}}} + r_{I_{IC_{1ad}}})\vec{H}_{IC_{1ad}}
\]
\[
\frac{d\vec{H}_{IC_{1vd}}}{dt} = i_{2} \vec{C}_{1vd} - (d_{H_{IC_{1vd}}} + r_{I_{IC_{1vd}}})\vec{H}_{IC_{1vd}}
\]
\[
\frac{d\vec{H}_{IC_{1vd}}}{dt} = i_{2} \vec{C}_{1vd} - (d_{H_{IC_{1vd}}} + r_{I_{IC_{1vd}}})\vec{H}_{IC_{1vd}}
\]
\[
\frac{d\vec{H}_{IC_{1vd}}}{dt} = i_{2} \vec{C}_{1vd} - (d_{H_{IC_{1vd}}} + r_{I_{IC_{1vd}}})\vec{H}_{IC_{1vd}}
\]
\[
\frac{d\vec{H}_{IC_{1vd}}}{dt} = i_{2} \vec{C}_{1vd} - (d_{H_{IC_{1vd}}} + r_{I_{IC_{1vd}}})\vec{H}_{IC_{1vd}}
\]
\[
\frac{d\vec{D}}{dt} = d(\vec{I} + \vec{H} + \vec{H}_{IC_{1ad}} + \vec{H}_{IC_{1vd}} + \vec{H}_{IC_{1vd}} + \vec{H}_{IC_{1vd}})
\]
\[
+ d_{IC}(\vec{I} + \vec{C} + \vec{C}_{1ad} + \vec{C}_{1vd} + \vec{C}_{1vd} + \vec{C}_{1vd} + \vec{C}_{1vd} + \vec{C}_{1vd})
\]
\[
+ d_{H_{IC}}(\vec{H}_{IC_{1ad}} + \vec{H}_{IC_{1vd}} + \vec{H}_{IC_{1vd}} + \vec{H}_{IC_{1vd}} + \vec{H}_{IC_{1vd}} + \vec{H}_{IC_{1vd}})
\]
\[
\frac{d\vec{R}}{dt} = \gamma I + r_{E} + r_{I_{E}}\vec{H}_{IC_{1ad}} - 4\omega R
\]
\[
\frac{d\vec{R}_{1vd}}{dt} = \gamma I_{1vd} + r_{E_{1vd}} + r_{I_{E}}\vec{H}_{IC_{1vd}} - 4\omega R_{1vd}
\]
\[
\frac{d\vec{R}_{2vd}}{dt} = \gamma I_{2vd} + r_{E_{2vd}} + r_{I_{E}}\vec{H}_{IC_{1vd}} - 4\omega R_{2vd}
\]
\[
\frac{d\vec{R}_{3vd}}{dt} = \gamma I_{3vd} + r_{E_{3vd}} + r_{I_{E}}\vec{H}_{IC_{1vd}} - 4\omega R_{3vd}
\]
\[
\frac{d\vec{R}_{4vd}}{dt} = \gamma I_{4vd} + r_{E_{4vd}} + r_{I_{E}}\vec{H}_{IC_{1vd}} - 4\omega R_{4vd}
\]
\[
\frac{d\vec{R}_{5vd}}{dt} = \gamma I_{5vd} + r_{E_{5vd}} + r_{I_{E}}\vec{H}_{IC_{1vd}} - 4\omega R_{5vd}
\]
\[
\frac{d\vec{R}_{1}}{dt} = 4\omega R - 4\omega R_{1}
\]
\[
\frac{d\vec{R}_{1}}{dt} = 4\omega R_{1vd} - 4\omega R_{1vd}
\]
\[
\frac{d\vec{R}_{1}}{dt} = 4\omega R_{1vd} - 4\omega R_{1vd}
\]
\[
\frac{d\vec{R}_{1}}{dt} = 4\omega R_{1vd} - 4\omega R_{1vd}
\]
\[
\frac{d\vec{R}_{1}}{dt} = 4\omega R_{1vd} - 4\omega R_{1vd}
\]
\[
\frac{d\vec{R}_{2}}{dt} = 4\omega R - 4\omega R_{2}
\]
\[
\frac{d\vec{R}_{2}}{dt} = 4\omega R_{2vd} - 4\omega R_{2vd}
\]
\[
\frac{d\vec{R}_{2}}{dt} = 4\omega R_{2vd} - 4\omega R_{2vd}
\]
\[
\frac{d\vec{R}_{2}}{dt} = 4\omega R_{2vd} - 4\omega R_{2vd}
\]
\[
\frac{d\vec{R}_{2}}{dt} = 4\omega R_{2vd} - 4\omega R_{2vd}
\]
\[
\frac{d\bar{R}^2}{dt} = 4\omega R^2_{td} - 4\omega R^2_{vd}
\]

\[
\frac{d\bar{R}^3}{dt} = 4\omega R^2_{td} - 4\omega R^3
\]

\[
\frac{d\bar{R}^2_{vd}}{dt} = 4\omega R^2_{td} - 4\omega R^3_{vd}
\]

\[
\frac{d\bar{R}^3_{vd}}{dt} = 4\omega R^2_{td} - 4\omega R^3_{vd}
\]

\[
\frac{d\bar{R}^3_{td}}{dt} = 4\omega R^2_{td} - 4\omega R^3_{td}
\]

\[
\frac{d\bar{R}^3_{vd}}{dt} = 4\omega R^2_{td} - 4\omega R^3_{vd}
\]

\[
\frac{d\bar{R}^3_{td}}{dt} = 4\omega R^2_{td} - 4\omega R^3_{td}
\]

**Outcome Equations**

Daily infections = \(\lambda (\bar{S} + \bar{S}_{\text{hold}}) + \eta_1 (\bar{S}_{vd} + \bar{S}_{\text{hold}vd}) + \eta_2 (\bar{S}_{vd} + \bar{S}_{\text{hold}vd}) + \eta_3 (\bar{S}_{vd} + \bar{S}_{\text{hold}vd}) + \eta_4 (\bar{S}_{td} + \bar{S}_{\text{hold}td}) + \eta_5 (\bar{S}_{vd} + \bar{S}_{\text{hold}vd}) \]

Daily cases = \(\sigma (E + \bar{E}_{vd} + \bar{E}_{\text{hold}vd} + \bar{E}_{vd} + \bar{E}_{\text{hold}vd})\) \(p_{\text{ascertainment}}\)

Hospital admissions = \(h (I + \eta_{\text{hosp}} I_{vd} + \eta_{\text{hosp}} I_{\text{hold}vd} + \eta_{\text{hosp}} I_{vd} + \eta_{\text{hosp}} I_{\text{hold}vd})\)

IC admissions = \(i_{\text{i}} (I + \bar{I}_{vd} + \bar{I}_{\text{hold}vd} + \bar{I}_{vd} + \bar{I}_{\text{hold}vd})\)

Daily Deaths = \(d (\bar{I} + \bar{H}_{vd} + \bar{H}_{\text{hold}vd} + \bar{H}_{vd} + \bar{H}_{\text{hold}vd}) + d_\text{IC} (\bar{IC} + \bar{IC}_{vd} + \bar{IC}_{\text{hold}vd} + \bar{IC}_{vd} + \bar{IC}_{\text{hold}vd}) + d_\text{IC} (\bar{IC}_{vd} + \bar{IC}_{\text{hold}vd} + \bar{IC}_{vd} + \bar{IC}_{\text{hold}vd} + \bar{IC}_{vd} + \bar{IC}_{\text{hold}vd})\)

The model is designed to incorporate a single vaccine product with a 2-dose regimen that 1) reduces susceptibility to infection, 2) reduces risk of hospitalization if a vaccinated individual is infected, and 3) reduces risk of infecting others (transmission) if a vaccinated person is infected. However, since there are more than one vaccine products currently licensed for use against COVID-19 in The Netherlands (the vaccines made by Pfizer/BioNTech, Moderna, AstraZeneca, and Janssen), we incorporate different vaccine products by taking the daily weighted average of the number of people with each vaccine product (and dose), the corresponding delay to protection of each vaccine product, and the vaccine effectiveness against each outcome (Table S1). Janssen is incorporated by using zero for the number of second doses at all time points. The weighted average of the VE can be expressed as:

\[
VE_{\text{wgt}d}(t) = \sum_{i=1}^{4} \frac{n_{di}(t)}{\sum_{i=1}^{4} n_{di}(t)} \times VE_{doit}
\]

where \(n_{di}(t)\) is the number of vaccines given as dose \(d\) (\(d = 1, 2\)) from vaccine product \(i\) (\(i = 1, 2, 3, 4\)) at time \(t\) and \(VE_{doit}\) is the VE against outcome \(o\) (\(o = \text{infection, hospitalization, transmission}\)), for dose \(d\), from vaccine product \(i\).

When VE is assumed to wane, we include the amount of waning as a logistic function parameterized so that after 6 months vaccine-induced protection is reduced by 50% and reduced by 100% after 1 year. The amount of waning is calculated at a given time since vaccination as

\[
\omega(t) = \frac{1}{1 + e^{-(k(t-t_0))}}
\]

where \(k\) is the logistic growth rate (here, \(k = 0.03\)), \(t\) is the time since vaccination in days, and \(t_0\) is the time point (in days) where 50% reduction occurs (here, \(t_0=180\)).

Then at each timepoint, VE with waning \((VE_{\omega}(t))\) is calculated as

\[
VE_{\omega}(t) = VE(t) - (VE(t)\omega(t))
\]

If \(VE(t)\omega(t) > VE(t)\), then \(VE_{\omega}(t) = 0\).
Rate of vaccination for each day, vaccine product, and dose for each age group is a model input. Increase of vaccination coverage over time was based on weekly data of allocated vaccines (up to 16 June 2021) or projected available vaccines (after 16 June 2021) by vaccine type, dose number, and target group (split up between healthcare workers, residents in institutions, chronically ill, and, if not part of one of the aforementioned groups, by age in 10-years age-bands) [1]. Projected final vaccination coverages were assumed at 90% for ≥70-year-olds and residents in institutions, 85% for 60- to 69-years-olds, health care workers and high-risk individuals, and 75% for others below 60 years of age. It was assumed that available vaccines were administered immediately until a target group reached the final coverage.

To account for the seasonal pattern of SARS-CoV-2 whereby, transmission is lower in summer and higher in winter, we define the transmission rate at time \( t \), \( \beta(t) \), as a sinusoidal function of seasonality [2]:

\[
\beta(t) = \beta_0 \left[ 1 + \beta_1 \cos \left( 2\pi \frac{t}{365.25} \right) \right].
\]

\( \beta_0 \) is a baseline (non-seasonal) transmission rate, \( \beta_1 \) is the amplitude of seasonal forcing, and \( t \) is the day of the year. We assume \( \beta_1 = 0.14 \). The baseline transmission rate \( \beta_0 \) and initial conditions for forward simulations are estimated by fitting the model to daily cases from the national notification database Osiris from 01 January 2020 to 22 June 2021, when vaccination in 12-17 year olds began in The Netherlands (Figure S2). The model is fitted to data piecewise to correspond with the correct contact patterns associated with different non-pharmaceutical interventions within each time window (Table S2). We directly estimate effective reproduction number (\( R_t \)) within each time window using maximum likelihood estimation. We assume daily cases follow a negative binomial distribution with mean \( \mu \) and overdispersion parameter \( \phi \). Estimates of \( R_t \) are converted to transmission rate by: \( \beta_0 = \frac{R_t}{\rho} \gamma \), where \( \gamma \) is the inverse of the infectious period and \( \rho \) is the dominant eigenvalue of the product of the diagonal matrix of the number of susceptibles and the transmission matrix. The transmission matrix is determined by multiplying the rows and columns of the contact matrix by estimates of the relative susceptibility and infectiousness of each age group compared to the 0-9 years age group (Table S4).

The amplitude of seasonal forcing \( \beta_1 \) is estimated by linear regression:

\[
\log \left( \frac{R_t}{s(t)} \right) = b_0 + b_1 X_{AH} + b_2 X_{temp} + b_3 X_{mobility} + b_4 X_{variant} + b_5 X_{day} + b_6 X_{intervention}
\]

The response variable is the logarithm of the effective reproduction number \( R_t \) [3] divided by the fraction susceptible \( s(t) \). The fraction susceptible is estimated from the cumulative age-specific hospitalizations at time \( t \) divided by age-specific hospitalization rates, which were in turn estimated from seroprevalences after the first wave in The Netherlands [3]. The explanatory variables for seasonal changes are absolute humidity (\( X_{AH} \)) and temperature in degrees Celsius (\( X_{temp} \)) [4]. Additional explanatory variables that may affect \( R_t \) were also included: percent change in mobility from "workplace" and "retail and recreation" (\( X_{mobility} \)) [5], increased transmissibility due to change in circulating virus variants (notably alpha and delta) (\( X_{variant} \)) [6], day of the week (\( X_{day} \)), and intervention period (\( X_{intervention} \)). Intervention period is a variable indicating 2-week to 2-month time periods during the epidemic without change in control measures. New periods started 2020-03-13, 2020-05-06, 2020-06-01, 2020-07-01, 2020-09-29, 2020-10-26, 2020-12-21, 2021-01-23, 2021-02-08, 2021-03-01, 2021-04-26, 2021-05-17, 2021-06-05. The seasonality curve was extracted from the intercept and seasonal variable coefficients only, from which the amplitude was determined by fitting a sinusoidal curve.
### Table S1. Vaccine effectiveness (VE) for each vaccine by dose based on observational studies.

| Outcome | Vaccine       | Age Group | VE dose 1 | VE dose 2 | Reference |
|---------|---------------|-----------|-----------|-----------|-----------|
| **Infection** | Pfizer/BioNTech | 0-11      | 57%       | 88%       | [7,8]     |
|         |               | 12-29     | 57%       | 88%       |           |
|         |               | 30-49     | 57%       | 84%       |           |
|         |               | 50-69     | 57%       | 83%       |           |
|         |               | 70+       | 57%       | 73%       |           |
|         | Moderna       | 0-11      | 66%       | 90%       |           |
|         |               | 12-29     | 66%       | 90%       |           |
|         |               | 30-49     | 66%       | 87%       |           |
|         |               | 50-69     | 66%       | 89%       |           |
|         |               | 70+       | 66%       | 86%       |           |
|         | AstraZeneca   | 0-11      | 41%       | 73%       |           |
|         |               | 12-29     | 41%       | 73%       |           |
|         |               | 30-49     | 41%       | 76%       |           |
|         |               | 50-69     | 41%       | 79%       |           |
|         |               | 70+       | 41%       | 76%       |           |
|         | Janssen       | 0-11      | 66%       | --        |           |
|         |               | 12-29     | 66%       | --        |           |
|         |               | 30-49     | 70%       | --        |           |
|         |               | 50-69     | 73%       | --        |           |
|         |               | 70+       | 78%       | --        |           |
| **Hospitalization** | Pfizer/BioNTech | 0-11      | 95%       | 98%       | [9]       |
|         |               | 12-29     | 95%       | 98%       |           |
|         |               | 30-49     | 95%       | 98%       |           |
|         |               | 50-69     | 94%       | 97%       |           |
|         |               | 70+       | 85%       | 88%       |           |
|         | Moderna       | 0-11      | 92%       | 97%       |           |
|         |               | 12-29     | 92%       | 97%       |           |
|         |               | 30-49     | 92%       | 97%       |           |
|         |               | 50-69     | 91%       | 96%       |           |
|         |               | 70+       | 86%       | 91%       |           |
|         | AstraZeneca   | 0-11      | 85%       | 90%       |           |
|         |               | 12-29     | 85%       | 90%       |           |
|         |               | 30-49     | 85%       | 90%       |           |
|         |               | 50-69     | 87%       | 93%       |           |
|         |               | 70+       | 69%       | 74%       |           |
|         | Janssen       | 0-11      | 94%       | --        |           |
|         |               | 12-29     | 94%       | --        |           |
|         |               | 30-49     | 94%       | --        |           |
|         |               | 50-69     | 95%       | --        |           |
|         |               | 70+       | 95%       | --        |           |
| **Transmission** | All            | All       | 46%       | 40%       | [10]      |

*a* A delay of protection is assumed to be 14 days after the first dose and 7 days after the second dose for the Pfizer/BioNTech, Moderna, and AstraZeneca vaccines and 28 days after the first dose of the Janssen vaccine.

*b* VE against hospitalization is incorporated as a multiplier on the probability of being hospitalized after infection as \((1 - \text{VE}_{\text{hospitalization}})/(1-\text{VE}_{\text{infection}})\) to account for the inclusion of people who are never infected (and thus never hospitalized) included in the estimation of VE against hospitalization.
Table S2. Timeline of measures and advice during the COVID-19 outbreak in the Netherlands.

| Date           | Control Measures                                                                                                                                 |
|----------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| 16/3/2020      | 1.5 meters distance rule begins  
                     All restaurants and bars are closed  
                     Sport/fitness clubs, saunas, sex clubs and coffeeshops are closed  
                     Schools and daycare facilities are closed. |
| 23/3/2020-24/3/2020 | Stay at home strongly encouraged  
                     Maximum of 3 visitors at home and keep distance  
                     Contact professions close  
                     All gatherings will be banned, except funerals, weddings and religious gatherings (maximum of 30 persons, 1.5 meter distance) |
| 11/5/2020      | Schools in primary education and day care can re-open with reduced capacity  
                     Contact professions and libraries can re-open  
                     Masks advised on public transport |
| 1/6/2020       | Masks mandatory on public transport  
                     Terraces re-open with 1.5 meter distance  
                     Cinemas, restaurants and cafes, and cultural re-open with maximum 30 persons (incl. staff) and 1.5 meters distance  
                     Secondary school partly re-open  
                     Vaccination begins |
| 8/6/2020       | Primary education reopens 100%. |
| 1/7/2020       | Secondary schools re-open at 100% capacity  
                     Fitness clubs, saunas, wellness centers, and casinos re-open  
                     The maximum number of visitors expanded to 100 people for cinemas, restaurants and cafes, cultural institutions |
| 6/8/2020       | Colleges and universities can open for small groups |
| 18/8/2020      | Allowed to receive a maximum of 6 people in the excluding children < 13 years old  
                     Home quarantine reduced from 14 to 10 days |
| 20/9/2020      | Large gathers limited to 50 people  
                     Some hospitality sectors must close at midnight or 1 AM |
| 29/9/2020      | Maximum 3 visitors allowed at home  
                     Large groups limited to 30 people  
                     Face masks advised for people >12 years old in public indoor areas |
| 14/10/2020     | Can receive a maximum of 3 visitors at home per day  
                     All cafes and restaurants close  
                     Retail stores close at 8 PM  
                     No team sports |
| 23/10/2020     | Hotels are not allowed to sell alcohol after 20.00 |
| 4/11/2020      | Can receive maximum of 2 visitors at home per day.  
                     Large groups, such as weddings, limited to 20 people |
| 19/11/2020     | Can receive a maximum of 3 people or 1 group at home per day.  
                     Large gathers limited to 30 people  
                     Work from home, unless there is no other option. |
| 1/12/2020      | Face masks mandatory on all public and indoor areas, in education, public transport and in contact professions. |
| 15/12/2020     | Only go outside with your household or in a group of max 2 people  
                     Receive a maximum of 2 people at home aged 13 or older  
                     Non-essential shops close |
| 20/1/2021 – 23/1/2021 | A curfew is introduced. Everyone stays indoors from 9 pm to 4.30 am.  
                     Do not travel or book trips that take place up to and including March 31. |
| 8/2/2021       | Primary schools, childcare and special education reopen.  
                     Out-of-school care (BSO) will remain closed |
| 1/3/2021 – 3/3/2021 | Secondary education and MBO will partly re-open  
                     Contact professions re-open  
                     People <27 years old can exercise together outside |
| 16/3/2021      | Retail stores re-open with reduced capacity |
| 31-3-2021      | The curfew will start at 10 PM instead of 9 PM.  
                     Stores that mainly sell food, such as supermarkets, close at 9:45 PM instead of 8:45 PM. |
| 19-4-2021      | The out-of-school care will be fully open again |
| 28-4-2021      | The curfew is canceled |
| Date        | Control Measures                                                                                                                                                                                                 |
|------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 19-5-2021  | Can receive a maximum of 2 people at home per day.  
Outdoor terraces open from 12:00 to 18:00 with maximum occupancy of 50 guests at 1.5 meter distance  
Retail stores re-open for walk-in shopping (no reservation needed) |
| 5-6-2014   | From the age of 27 sports outside in groups allowed at a distance of 1.5 meters. Max. 30 people per group.  
Indoor sports venues re-open  
Non-essential travel allowed within the Netherlands.  
Outdoor performance venues re-open  
Terraces can be open from 6:00 to 20:00  
Sex workers allowed to resume their profession  
Libraries re-open |
| 22-6-2021  | 4 visitors allowed at home per day.  
Museums and cultural institutions re-open  
Restaurants re-open  
Large groups limited to 50 people |
|            | Vaccination of 12-17 year olds begin                                                                                                                                  |

This is an abbreviated version of the timeline published at: [https://www.rijksoverheid.nl/onderwerpen/coronavirus-tijdslijn](https://www.rijksoverheid.nl/onderwerpen/coronavirus-tijdslijn)
| Parameter | Description                                      | Value        | Details                                                                 |
|-----------|--------------------------------------------------|--------------|-------------------------------------------------------------------------|
| $\beta$   | Transmission rate                                | Varies over time | This results in a latent period of 2 days                              |
| $\sigma$  | Inverse of the latent period                     | 0.5/day      | This results in an infectious period of 2 days                          |
| $\gamma$  | Inverse of the infectious period                 | 0.5/day      |                                                                         |
| $\lambda$ | Force of infection                               | Varies over time |                                                                         |
| $\epsilon$| Rate of case importation                         | 0.0/day      |                                                                         |
| $\alpha$  | Rate of vaccination with the first dose          | This depends on the vaccine allocation schedule and varies over time | Calculated as a composite rate of multiple vaccines                     |
| $\alpha_2$| Rate of vaccination with the second dose         | This depends on the vaccine allocation schedule and varies over time | Calculated as a composite rate of multiple vaccines                     |
| $\delta_1$| Delay to protection of first dose                | See Table S1 | With multiple vaccines, the weighted average is used                   |
| $\delta_2$| Delay to protection of second dose               | See Table S1 | With multiple vaccines, the weighted average is used                   |
| $\eta$    | 1 – vaccine efficacy of first dose               | See Table S1 | With multiple vaccines, the weighted average is used                   |
| $\eta_2$  | 1 – vaccine efficacy of second dose              | See Table S1 | With multiple vaccines, the weighted average is used                   |
| Parameter | Description | Age group | Value  | Details |
|-----------|-------------|-----------|--------|---------|
| \( h \)   | Rate from infectious to hospital | 0-9       | 0.0015 | Calculated as the probability of infection to hospital divided by time from symptoms to hospital: \( 0.00347/2.29 \) |
|           |             | 10-19     | 0.0001 |         |
|           |             | 20-29     | 0.0002 |         |
|           |             | 30-39     | 0.0007 |         |
|           |             | 40-49     | 0.0013 |         |
|           |             | 50-59     | 0.0028 |         |
|           |             | 60-69     | 0.0044 |         |
|           |             | 70-79     | 0.0097 |         |
|           |             | 80+       | 0.0107 |         |
| \( i_1 \) | Rate from hospital ward to IC | 0-9       | 0.0000 | Calculated as the probability of IC admission from hospital divided by average time from hospital admission to IC admission (2.28 days) |
|           |             | 10-19     | 0.0271 |         |
|           |             | 20-29     | 0.0422 |         |
|           |             | 30-39     | 0.0482 |         |
|           |             | 40-49     | 0.0719 |         |
|           |             | 50-59     | 0.0886 |         |
|           |             | 60-69     | 0.1070 |         |
|           |             | 70-79     | 0.0860 |         |
|           |             | 80+       | 0.0154 |         |
| \( i_2 \) | Rate from IC back to hospital ward | 0-9       | 0.0555 | Calculated as the probability of admission back to hospital ward from IC divided by average length of stay in IC (15.6 days) |
|           |             | 10-19     | 0.0555 |         |
|           |             | 20-29     | 0.0555 |         |
|           |             | 30-39     | 0.0555 |         |
|           |             | 40-49     | 0.0555 |         |
|           |             | 50-59     | 0.0531 |         |
|           |             | 60-69     | 0.0080 |         |
|           |             | 70-79     | 0.0367 |         |
|           |             | 80+       | 0.0356 |         |
| \( d \)  | Rate from hospital (before IC) to death | 0-9       | 0.0003 | Calculated as the probability of death from hospital admission divided by average length of time in hospital before death (7 days) |
|           |             | 10-19     | 0.0006 |         |
|           |             | 20-29     | 0.0014 |         |
|           |             | 30-39     | 0.0031 |         |
|           |             | 40-49     | 0.0036 |         |
|           |             | 50-59     | 0.0057 |         |
|           |             | 60-69     | 0.0151 |         |
|           |             | 70-79     | 0.0327 |         |
|           |             | 80+       | 0.0444 |         |
| \( d_{ic} \) | Rate from IC to death | 0-9       | 0.0071 | Calculated as the probability of death from IC divided by average length of time in IC before death (19 days) |
|           |             | 10-19     | 0.0071 |         |
|           |             | 20-29     | 0.0071 |         |
|           |             | 30-39     | 0.0071 |         |
|           |             | 40-49     | 0.0071 |         |
|           |             | 50-59     | 0.0090 |         |
|           |             | 60-69     | 0.0463 |         |
|           |             | 70-79     | 0.0225 |         |
|           |             | 80+       | 0.0234 |         |
| \( d_{bic} \) | Rate from hospital (after IC) to death | 0-9       | 0.0000 | Calculated as the probability of death from hospital ward (after IC) divided by average length of time in hospital ward (after IC) before death (10 days) |
|           |             | 10-19     | 0.0000 |         |
|           |             | 20-29     | 0.0000 |         |
|           |             | 30-39     | 0.0000 |         |
|           |             | 40-49     | 0.0000 |         |
|           |             | 50-59     | 0.0010 |         |
|           |             | 60-69     | 0.0040 |         |
|           |             | 70-79     | 0.0120 |         |
| Parameter | Description | Age group | Value | Details |
|-----------|-------------|-----------|-------|---------|
| $r$       | Rate of recovery from hospital (before IC) | 80+       | 0.0290| Calculated as $1 - \text{the probability of death from hospital admissions divided by the average time from hospital admission to discharge (7.9 days)}$ |
|           |             | 0-9       | 0.1263|         |
|           |             | 10-19     | 0.1260|         |
|           |             | 20-29     | 0.1254|         |
|           |             | 30-39     | 0.1238|         |
|           |             | 40-49     | 0.1234|         |
|           |             | 50-59     | 0.1215|         |
|           |             | 60-69     | 0.1132|         |
|           |             | 70-79     | 0.0976|         |
|           |             | 80+       | 0.0872|         |
| $r_{ir}$  | Rate of recovery from hospital (after IC) | 0-9       | 0.0857| Calculated as $1 - \text{the probability of death from hospital ward after IC divided by the average time from hospital ward (after IC) to discharge (10.1 days)}$ |
|           |             | 10-19     | 0.0857|         |
|           |             | 20-29     | 0.0857|         |
|           |             | 30-39     | 0.0857|         |
|           |             | 40-49     | 0.0857|         |
|           |             | 50-59     | 0.0821|         |
|           |             | 60-69     | 0.0119|         |
|           |             | 70-79     | 0.0567|         |
|           |             | 80+       | 0.0550|         |
| $p_{\text{ascertainment}}$ | Case ascertainment proportion | 0-9       | 0.2900|         |
|           |             | 10-19     | 0.3630|         |
|           |             | 20-29     | 0.3810|         |
|           |             | 30-39     | 0.5450|         |
|           |             | 40-49     | 0.6450|         |
|           |             | 50-59     | 0.5640|         |
|           |             | 60-69     | 0.3650|         |
|           |             | 70-79     | 0.3300|         |
|           |             | 80+       | 0.4090|         |
| Relative Susceptibility/ Infectiousness |          | 0-9       | 1.000 |         |
|           |             | 10-19     | 3.051 |         |
|           |             | 20-29     | 5.751 |         |
|           |             | 30-39     | 3.538 |         |
|           |             | 40-49     | 3.705 |         |
|           |             | 50-59     | 4.365 |         |
|           |             | 60-69     | 5.688 |         |
|           |             | 70-79     | 5.324 |         |
|           |             | 80+       | 7.211 |         |
Figure S1. Basic conceptual model diagram. This diagram does not include the additional states after the first set vaccinated states or the age structure in the model. $S =$ susceptible, $E =$ exposed, $I =$ infectious, $R =$ recovered, $R_x =$ additional recovered state $x$, $H =$ hospitalized, $IC =$ in intensive care, $HIC =$ return to the hospital ward following treatment in IC, $S_{hold} =$ vaccinated, but not yet protected, $D =$ dead. States with subscript $V$ indicate individuals who are vaccinated and protected by vaccination. $\lambda =$ force of infection, $\sigma =$ rate from exposed to infections, $\gamma =$ rate from infectious to recovered, $\omega =$ rate of waning from recovered back to susceptible, $\alpha =$ rate of vaccination, $\delta =$ delay period to protection from vaccination, $\eta =$ protection from vaccination against infection, $\eta_{hosp} =$ protection from vaccination against hospitalization, $h =$ rate from infectious to hospital, $i_1 =$ rate from hospital to intensive care, $i_2 =$ rate from intensive care back to hospital ward, $d =$ rate from hospital to death, $d_{IC} =$ rate from intensive care to death, $d_{HIC} =$ rate from hospital ward after intensive care to death, $r =$ rate of recovery from hospital, $r_{IC} =$ rate of recovery from hospital ward after intensive care.
Figure S2. Fit to case notification data with 95% confidence bounds
Figure S3. Vaccination coverage over time by dose, vaccine type, and age group for the different vaccination scenarios. A) vaccination coverage in 0-9 and 10-19 year old when everyone 5 years and above (5+) is vaccinated. B) vaccination coverage in 0-9 and 10-19 year old when everyone 12 years and above (12+) is vaccinated. C) vaccination coverage in 0-9 and 10-19 year old when everyone 18 years and above (18+) is vaccinated. D) vaccination coverage for adult age groups, (vaccination coverage in adults 20 years and above do not vary by vaccination scenario).
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