Modeling Vaccination

Interventions

- **Non-pharmaceutical interventions**
  - Sanitation
  - Social distancing
  - Masking
  - Education
- **Pharmaceutical interventions**
  - Therapeutics
    - Drugs, antivirals, antibody therapies
  - Prophylaxis
    - Vaccines, antibody therapies

What do vaccines do?

- **Vaccine:** A preparation that is used to stimulate the body's immune response against pathogens.
- **Efficacy:** measured in a controlled clinical trial and is based on how many people who got vaccinated developed the 'outcome of interest' (usually disease) compared with how many people who got the placebo developed the same outcome.
- **Effectiveness:** a measure of how well vaccination works under real-world conditions to protect people against health outcomes such as infection, symptomatic illness, hospitalization, and death.

What do vaccines do?

- **Prevent infection** – move you from S -> R
  - Measles, Oral polio vaccine
- **Prevent illness** – perhaps still transmission?
  - Inactivated polio vaccine, diphtheria
- **Prevent/reduce transmission** –> reduce Beta
  - SARS-CoV-2, RTS,s
- **Accelerate clearance** –> shorten L
  - SARS-CoV-2

How long does immunity last? For simplicity now, we'll assume that immunity is lifelong

Herd Immunity

- Indirect protection to non-immune individuals due to the presence of immune individuals in the population

Critical Herd Immunity Threshold

- When indirect protection is high enough, the risk to non-immune individuals falls to 0 because the endemic equilibrium is 0

Critical Herd Immunity Threshold

$$R_0 = \frac{\beta S}{\gamma} = \beta S L$$

$$R_0 = \beta S L$$

$$1 = \frac{\beta S L}{R_0}$$

$$1 = \frac{1}{R_0} S \beta L$$

What fraction of Susceptibles need to be immune in order for

$$\frac{1}{R_0} S$$

to remain?

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$$T_c = 1 - \frac{1}{R_0}$$

Imperfect Vaccine Effectiveness

$$T_C = 1 - \frac{1}{R_0}$$

$$T_C = P(\text{vaccinated}) * \text{effectiveness}$$

$$P(\text{vaccinated}) = \frac{1}{\text{effectiveness}}\left(1 - \frac{1}{R_0}\right)$$

T_C are those effectively immunized. We must account for vaccine failure

THE LANCET
Respiratory Medicine

NEWS | ONLINE FIRST

Omicron variant and booster COVID-19 vaccines

Talha Khan Burki

Published: December 17, 2021 • DOI: https://doi.org/10.1016/S2213-2600(21)00559-2 •

The original strain of SARS-CoV-2 has an R0 of 2·5, while the delta variant (B.1.617.2) has an R0 of just under 7. Martin Hibberd, professor of emerging infectious diseases at London School of Hygiene & Tropical Medicine (London, UK), reckons omicron's R0 could be as high as 10. In the UK, cases of omicron are doubling

Imperfect Vaccine Effectiveness

$$T_C = 1 - \frac{1}{R_0}$$

$$T_C = P(\text{vaccinated}) * \text{effectiveness}$$

$$P(\text{vaccinated}) = \frac{1}{\text{effectiveness}}\left(1 - \frac{1}{R_0}\right)$$

(ex) Assume R0:

OG SARS-CoV-2 is 2.5

Delta is 7

Omicron is 10

What fraction of the population needs to be vaccinated if we have a vaccine that is 100%, 90%, 70% of 50% effective in blocking transmission?

Exercises

(ex) Assume R_0:

OG SARS-CoV-2 $R_0 = 2.5$: 60%

Delta is $R_0 = 7$: 86%

Omicron is $R_0 = 10$: 90%

What fraction of the population needs to be vaccinated if we have a vaccine that is 100% effective in blocking transmission?

Exercises

(ex) Assume R_0:

OG SARS-CoV-2 R_0 = 2.5: 60%, 67%, 86%, 120%

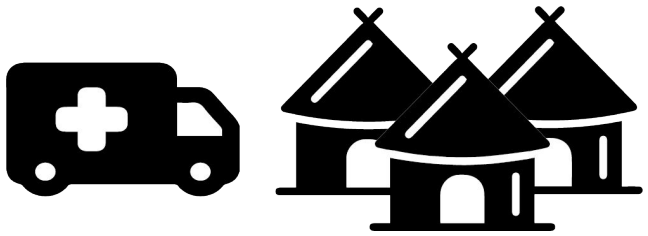
Delta is R_0 = 7: 86%, 95%, 122%,170%

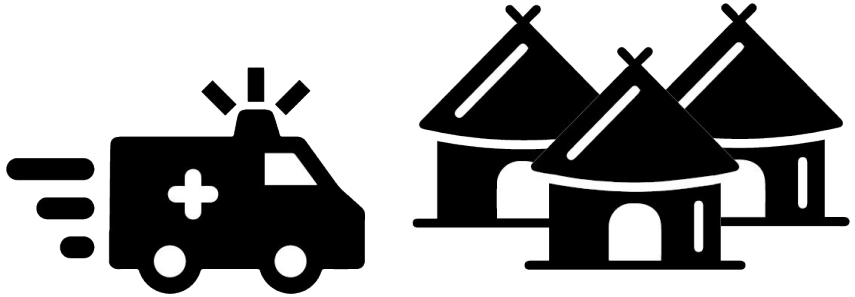
Omicron is R_0 = 10: 90%, 100%, 129%, 180%

What fraction of the population needs to be vaccinated if we have a vaccine that is 100%, 90%, 70% or 50% effective in blocking transmission?

How is vaccination delivered?

- Routine
  - 1st dose
  - 2nd , 3rd, etc dose … opportunity
- Supplemental immunization activities
- Outbreak response immunization





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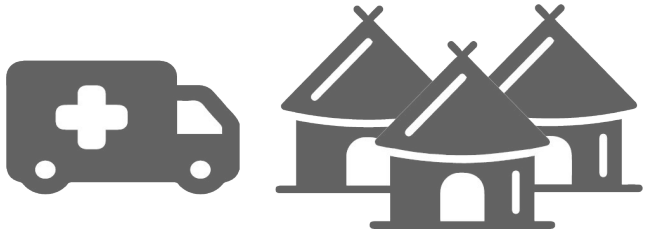
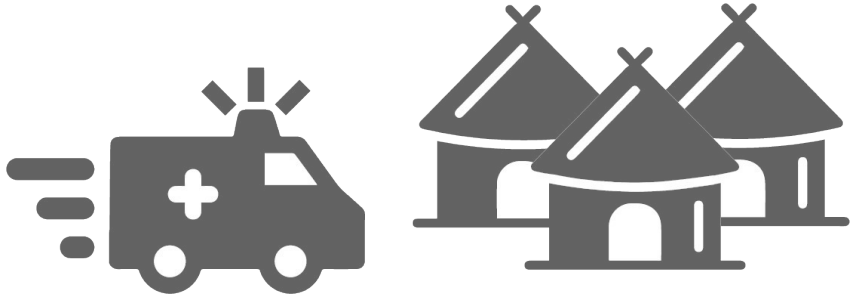
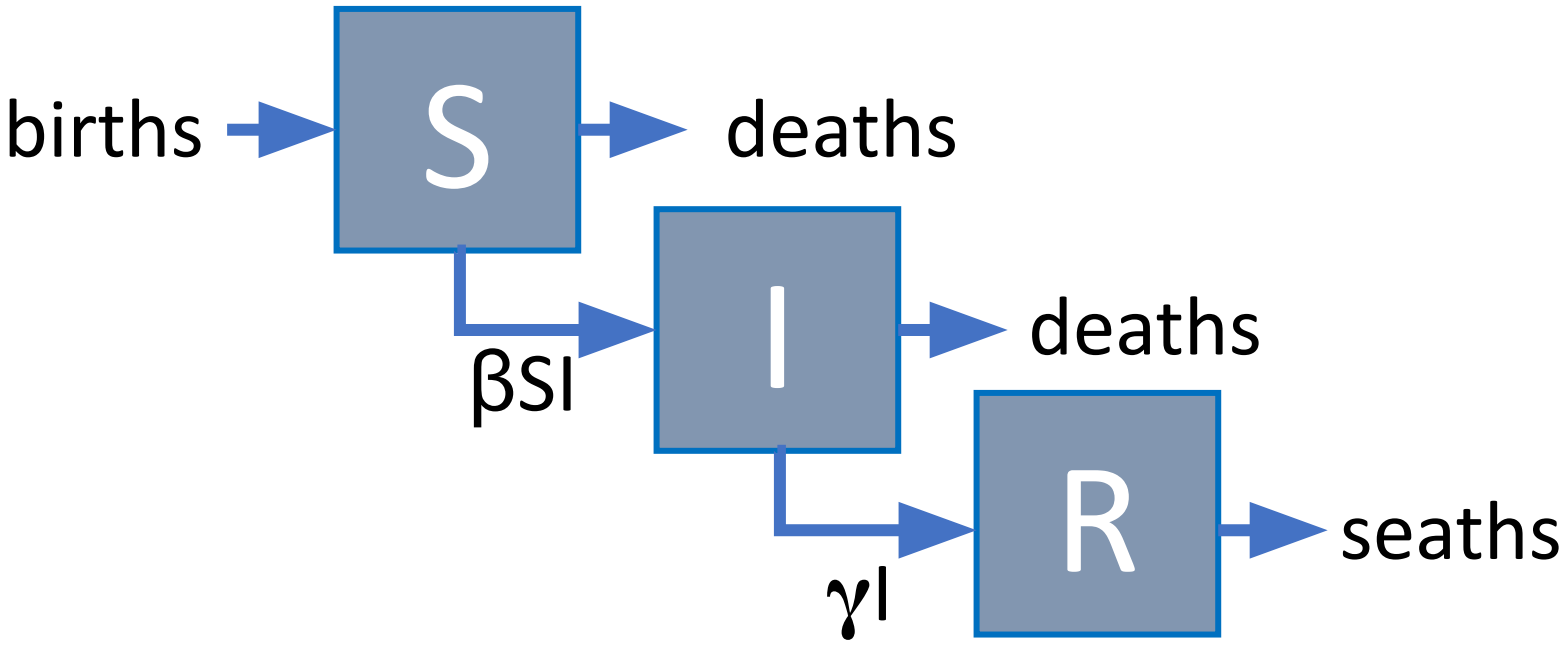




Vaccination with a single dose

How do we represent vaccination in models?



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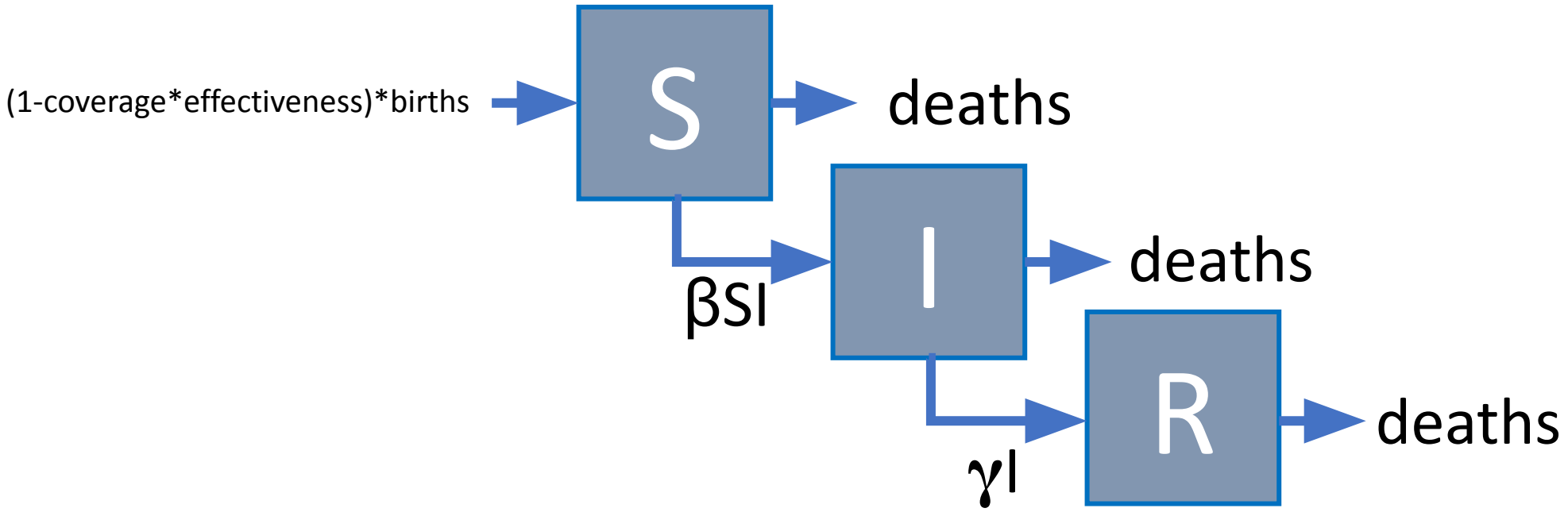

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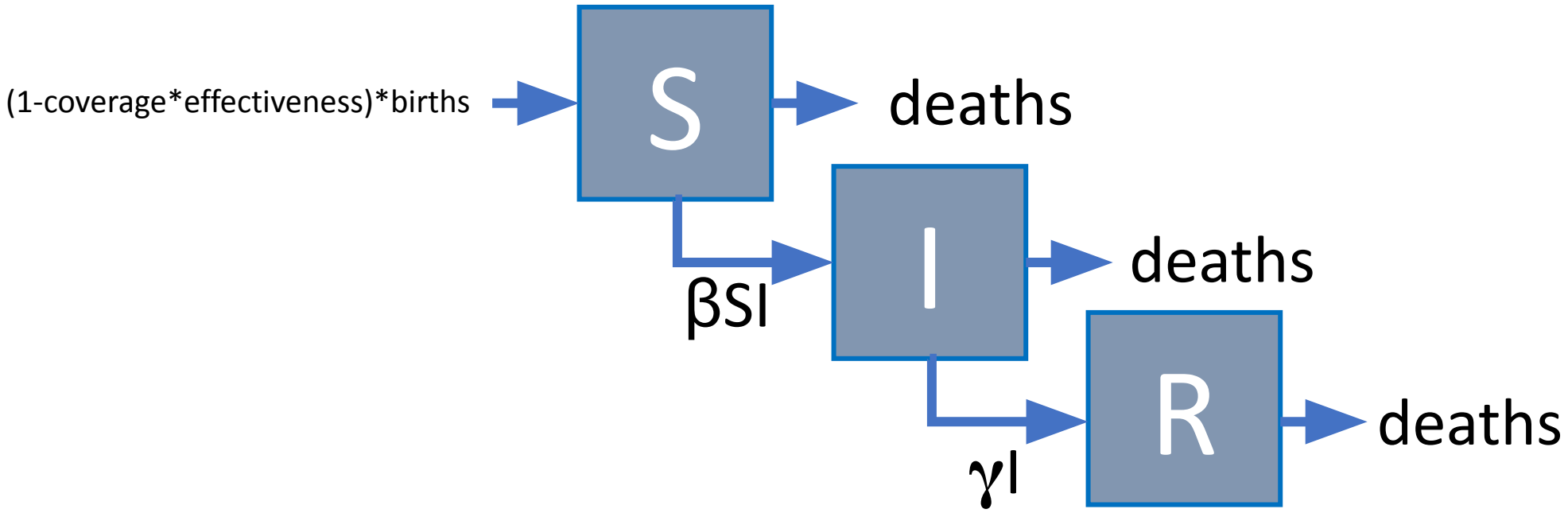
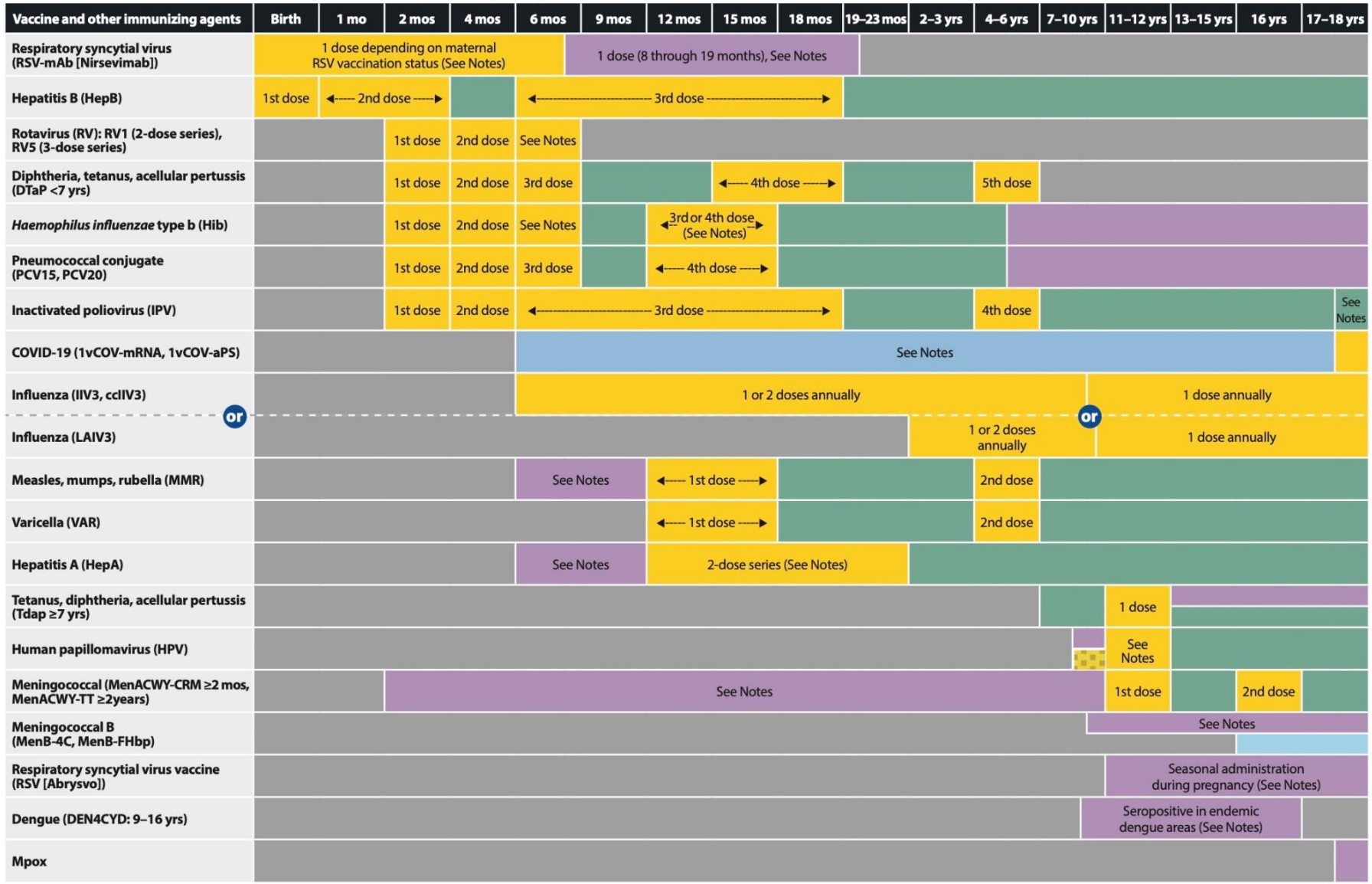


All models are approximations

Does this approximation seem reasonable?

Table 1 Recommended Child and Adolescent Immunization Schedule for Ages 18 Years or Younger, United States, 2025

These recommendations must be read with the notes that follow. For those who fall behind or start late, provide catch-up vaccination at the earliest opportunity as indicated by the green bars.
To determine minimum intervals between doses, see the catch-up schedule (Table 2).



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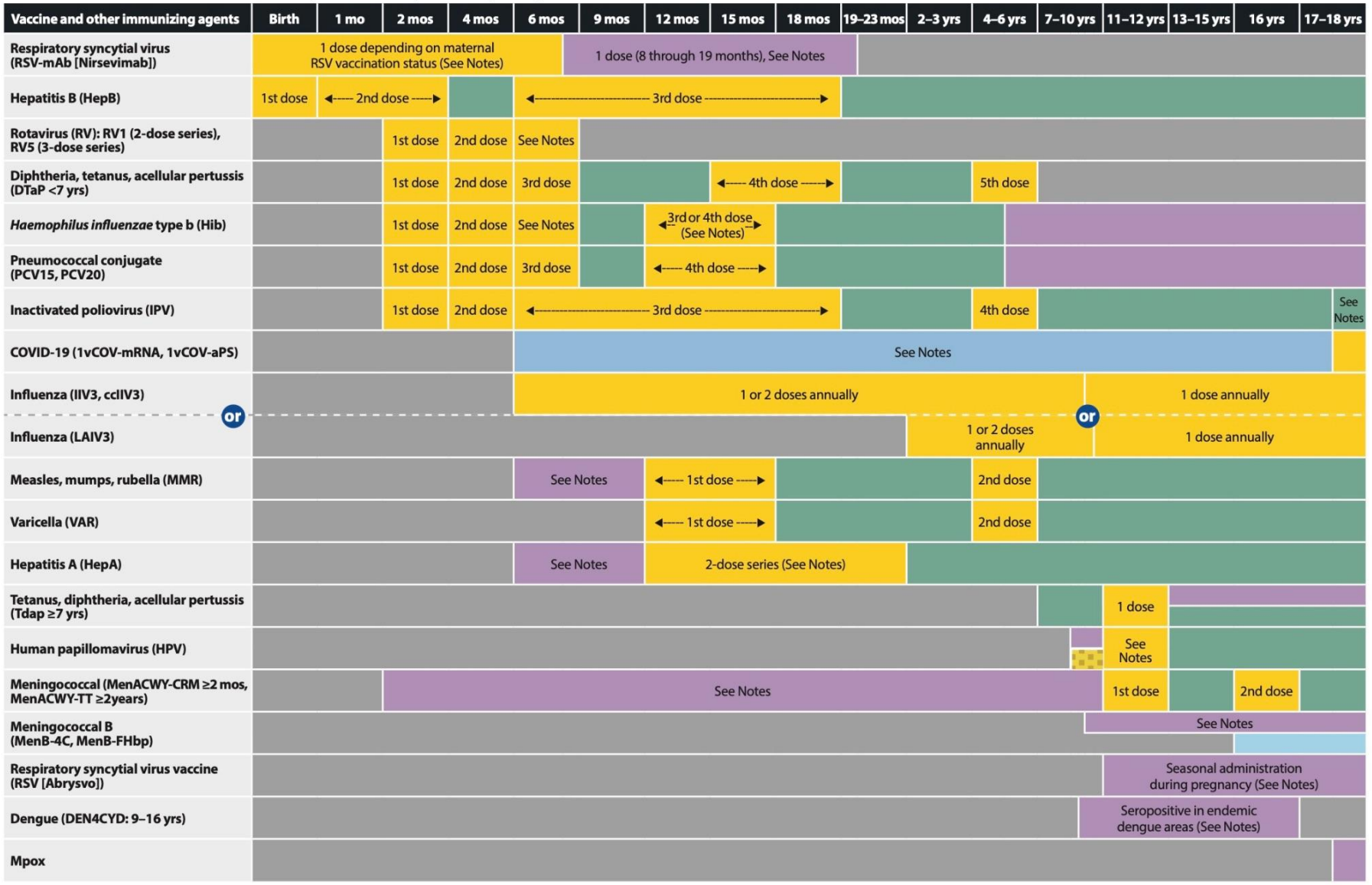

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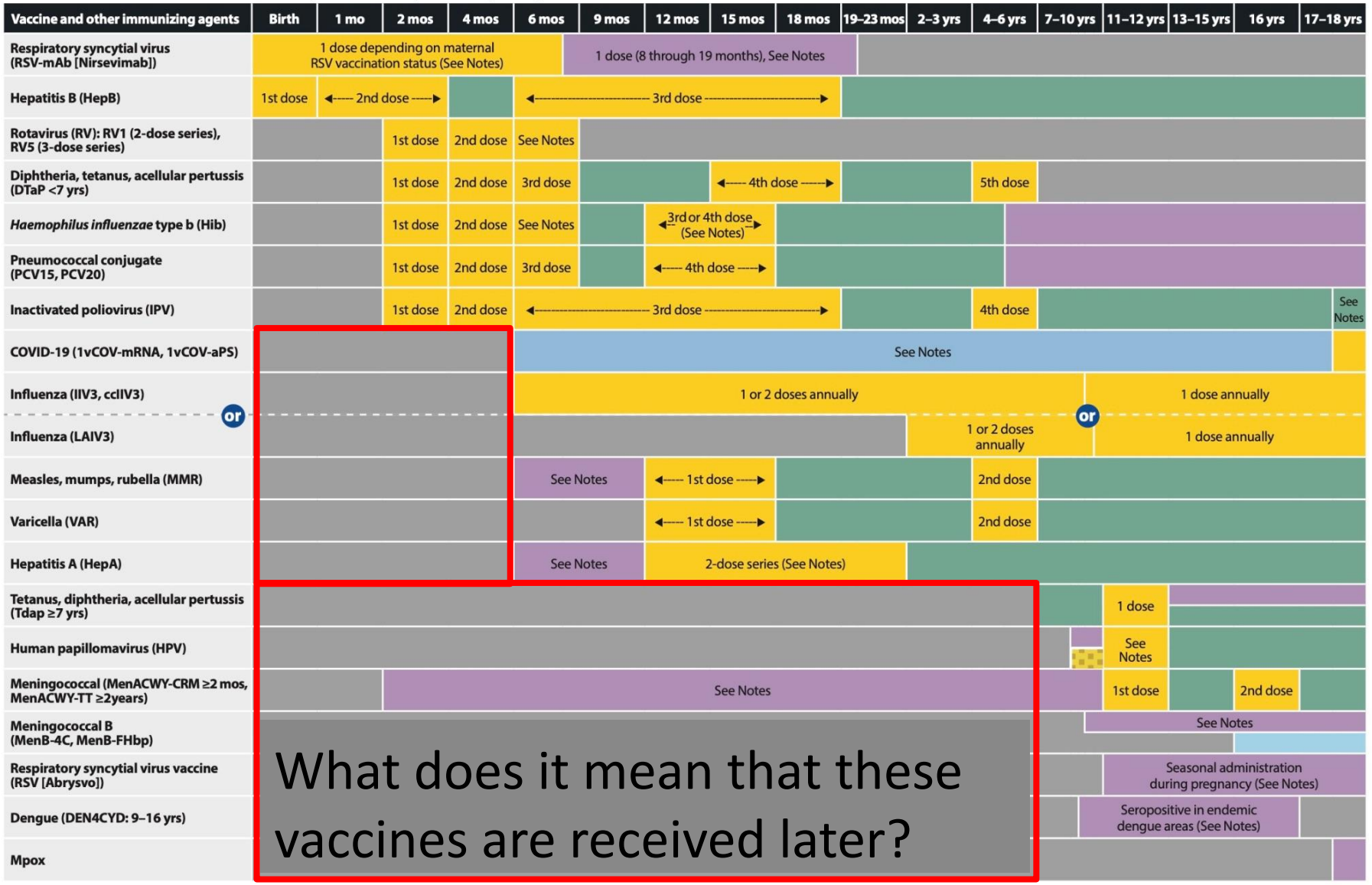
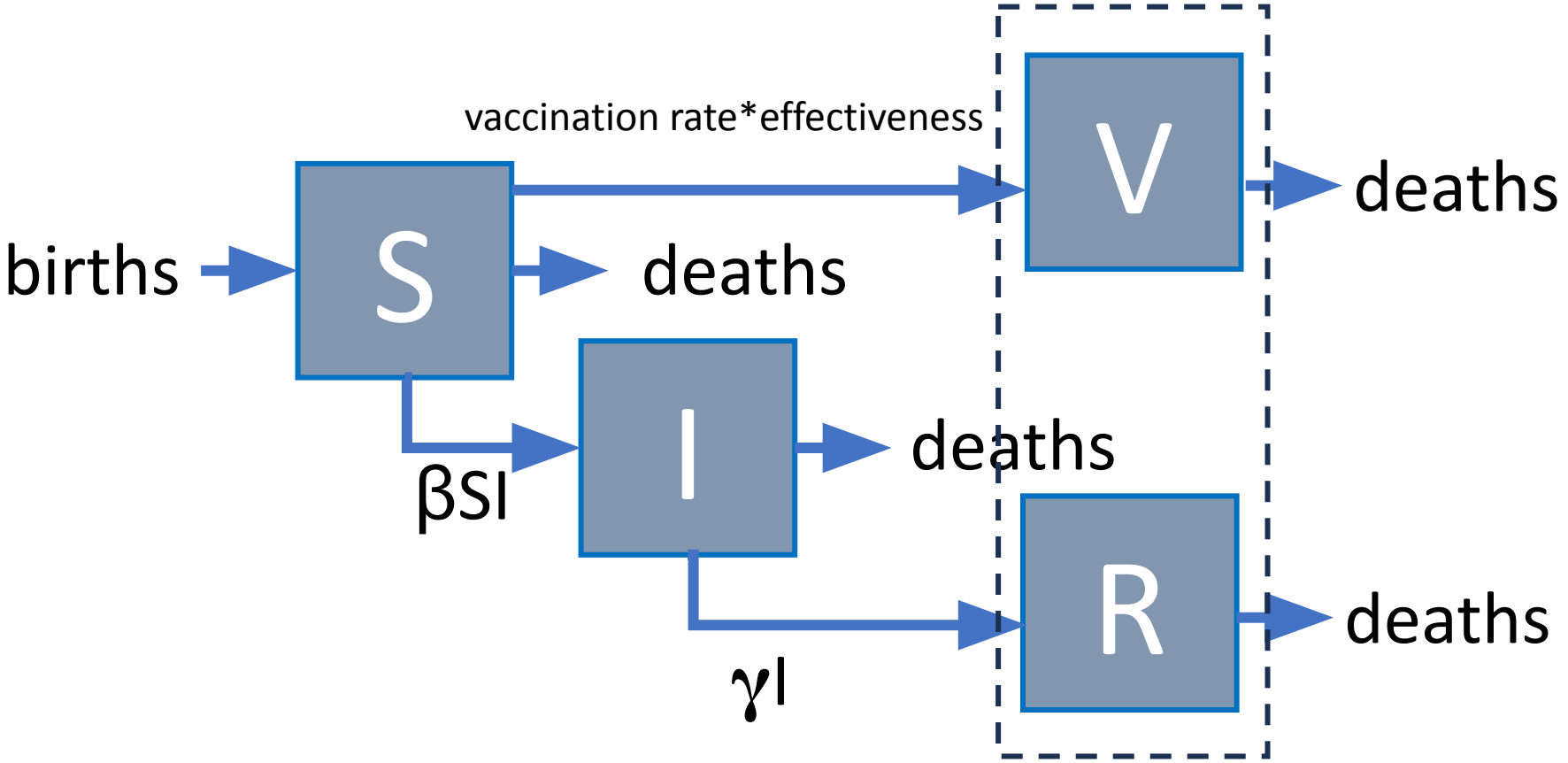


What does it mean that these vaccines are received later?

How do we represent vaccination in models?



Maternal Immunity

- Antibodies from immune mothers are passively transferred to infant
- Infant cannot produce new antibodies. Transferred antibodies (and immunity) degrades approximately exponentially.

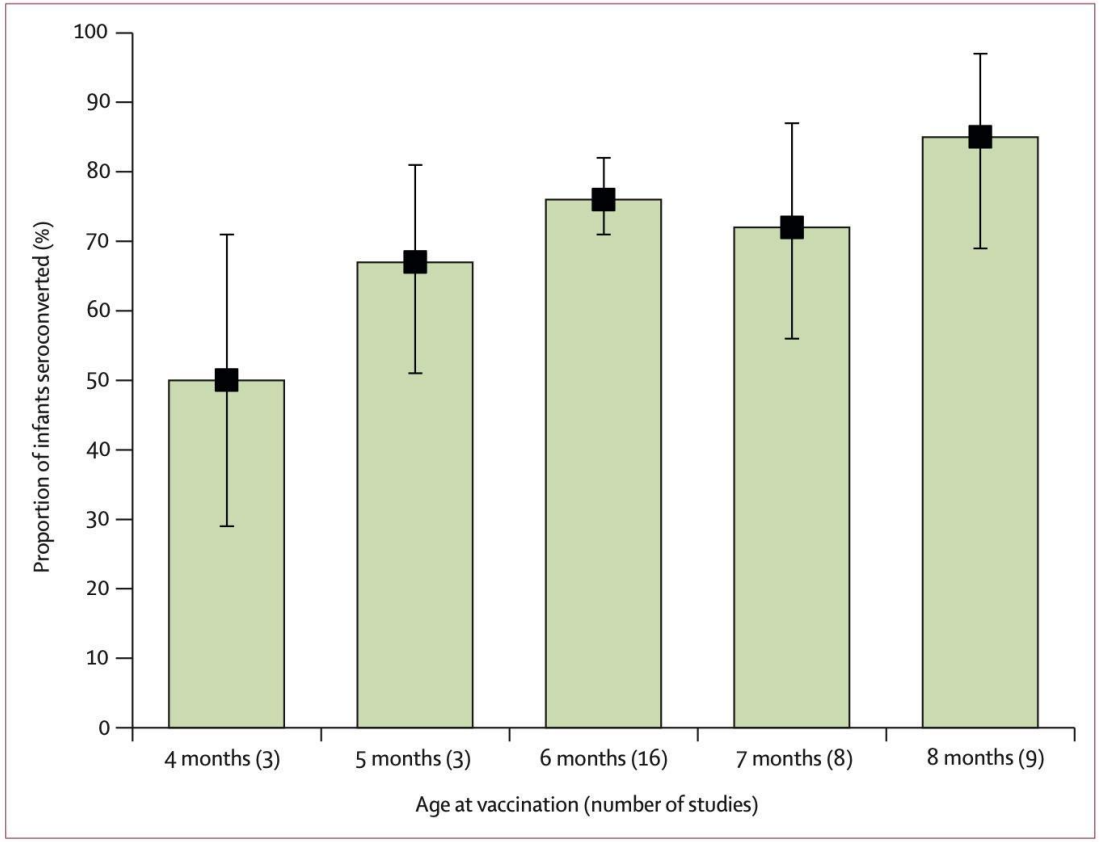
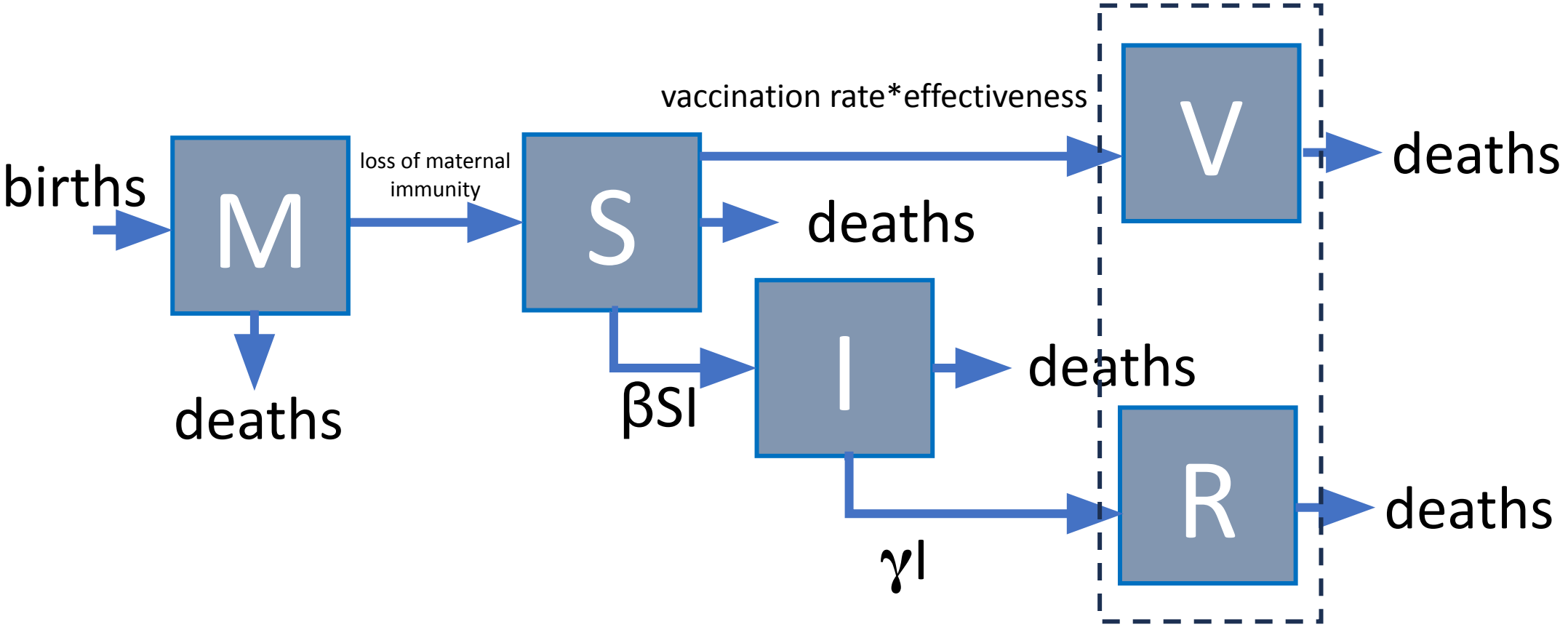


Figure 2: **Pooled estimates of proportion of infants seroconverted, by age of MCV1 (4–8 months) with 95% CIs**
MCV1=first dose of measles-containing vaccine.

Immunogenicity, effectiveness, and safety of measles vaccination in infants younger than 9 months: a systematic review and meta-analysis

Laura M Nic Lochlainn, Brechje de Gier, Nicoline van der Maas, Peter M Strebel, Tracey Goodman, Rob S van Binnendijk, Hester E de Melker, Susan J M Hahné

Adding a Maternal Immunity Class



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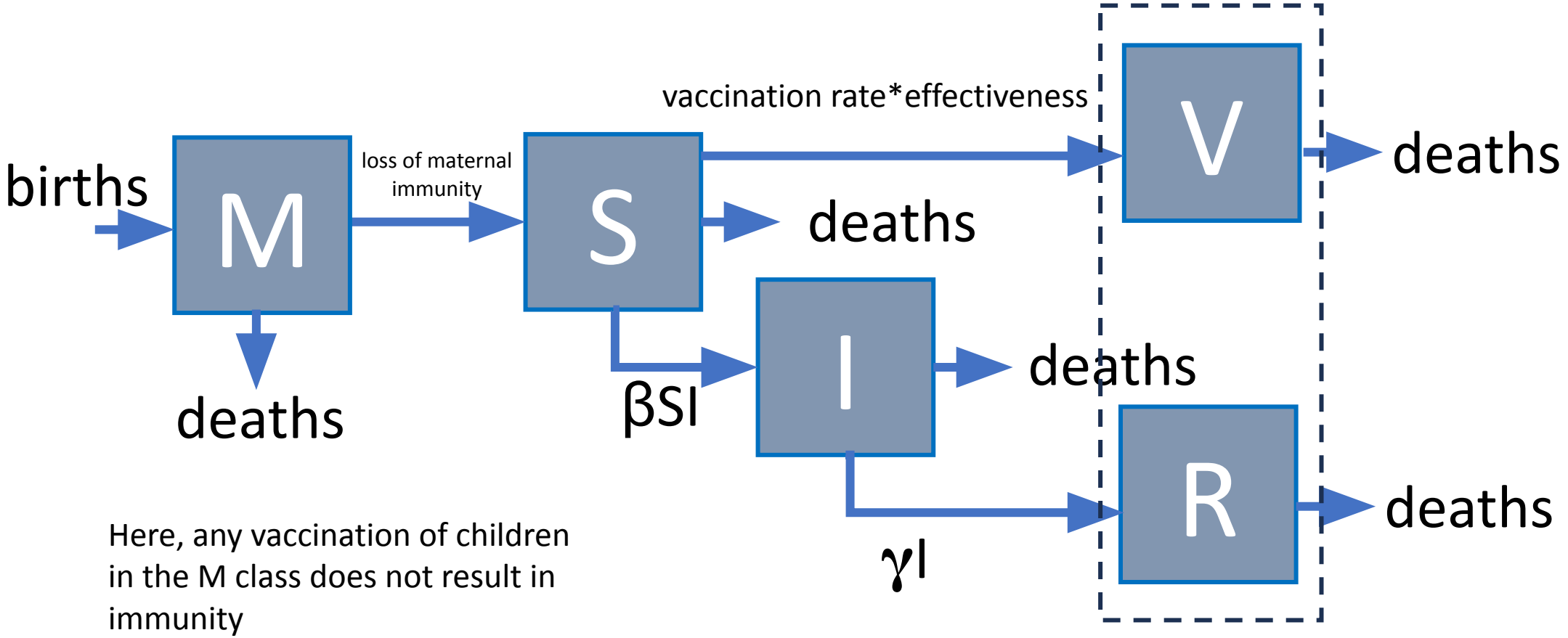
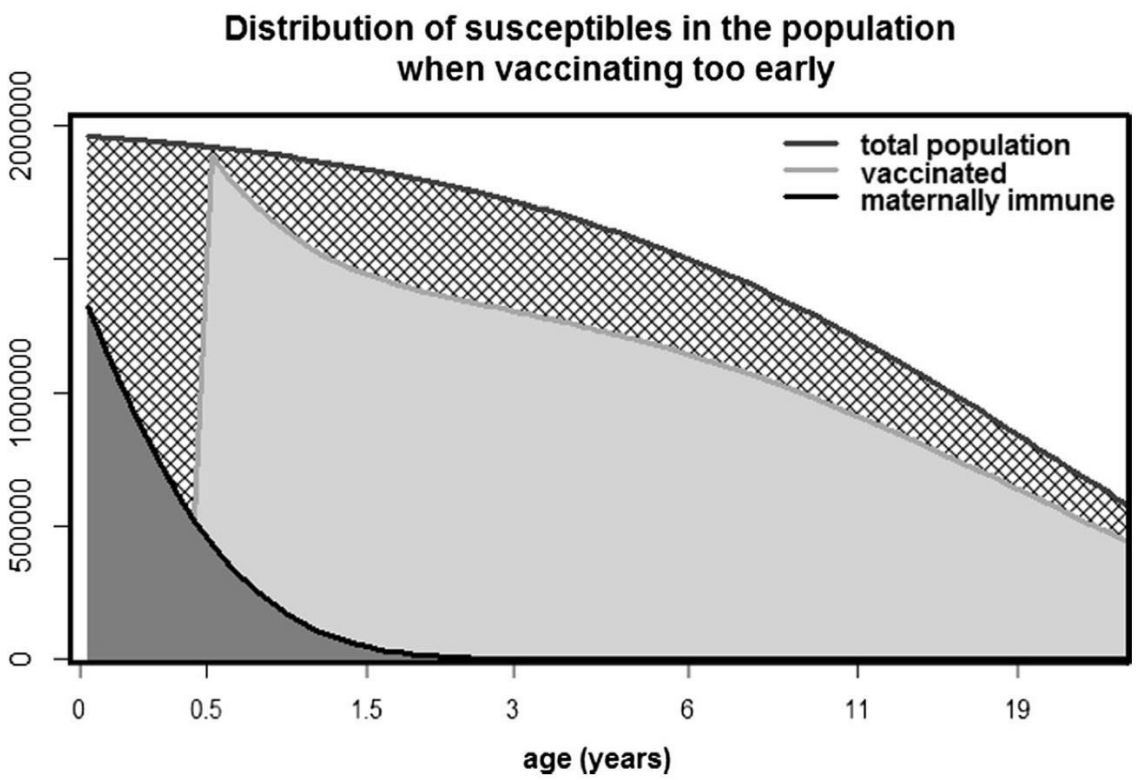
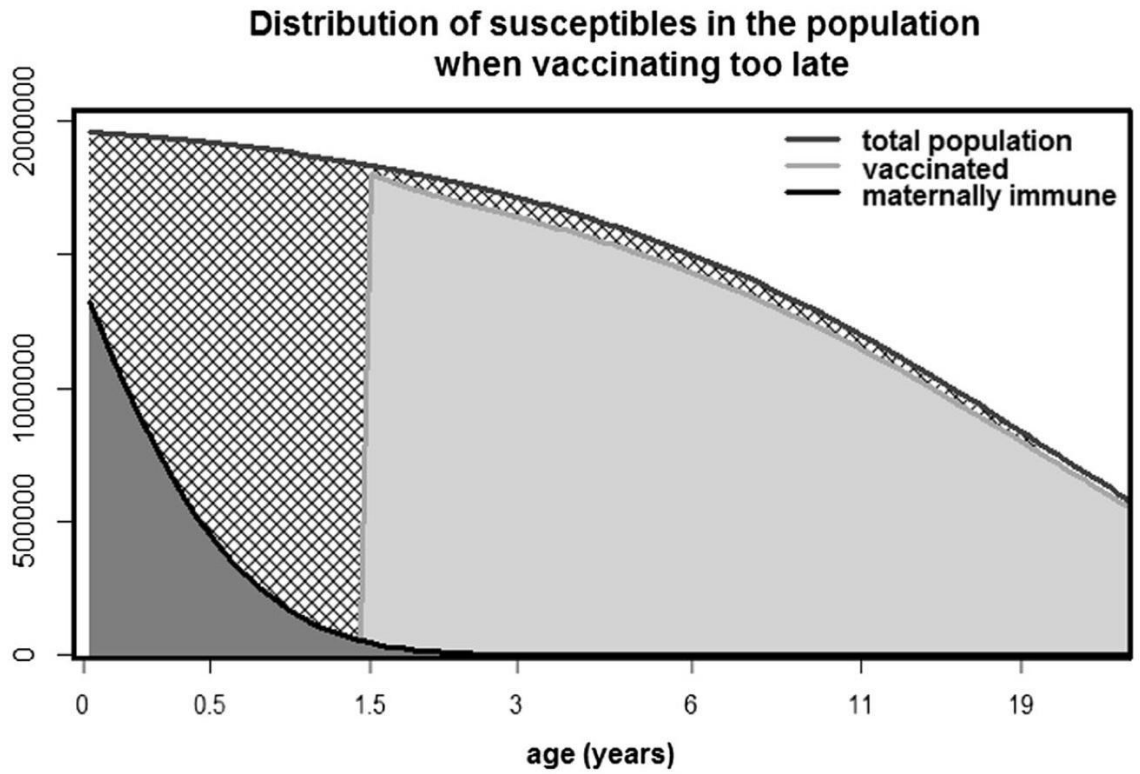


Here, any vaccination of children in the M class does not result in immunity

Timing of the First Dose

Label y axis





Second Doses

Second Doses

- Routine Immunization
- Supplemental Immunization
- Outbreak Response Immunization

Second Doses

- Routine Immunization (Measles as an example)
  - Delivered through “well-child” visits at targeted ages
  - 1st dose recommended at 9-12 months, timing dependent on prevalence
  - 2nd dose recommended at 24 months or higher, varies by country. Goal is immunize those who failed to seroconvert with first dose
  - Formally, 2nd dose coverage is recorded as the fraction of children with 1st dose that receive a 2nd dose. However, this convention is not universal.
- Supplemental Immunization
- Outbreak Response Immunization

Second Doses

- Routine Immunization
- Supplemental Immunization (SIA)
  - Periodic, large-scale vaccination of all children (regardless of prior vaccination) within a target age group.
  - Modeled after PAHO strategy of “catch up”, “keep up”, ”follow up”
  - Models have been useful in determining the frequency and age targets for these campaigns
  - Implementation in models as a single time point move from S to R, resulting in a large reduction in S class in the target age groups.
- Outbreak Response Immunization

Second Doses

- Routine Immunization
- Supplemental Immunization (SIA)
- Outbreak Response Immunization
  - Vaccination activities that are triggered by the occurrence of an outbreak
  - Indiscriminate targeting of all children within an age window (e.g. 6-59m)
  - Triggers (e.g. number of cases), speed, scale, and coverage of response varies by country and the organization conducting the ORI
  - Modelling has been useful in identifying age targets and evaluating the potential trade-offs between speed and coverage. As outbreak progresses there is less indirect (herd) benefit of each dose.