SBML Model Report

Model name: "Restif2007_Vaccination_Invasion"

May 6, 2016

1 General Overview

This is a document in SBML Level 2 Version 4 format. This model was created by Lukas Endler[1] at April 20th 2010 at 11:54 p. m. and last time modified at October 14th 2014 at 11:58 a. m. Table 1 provides an overview of the quantities of all components of this model.

Table 1: Number of components in this model, which are described in the following sections.

Element	Quantity	Element	Quantity
compartment types	0	compartments	1
species types	0	species	11
events	0	constraints	0
reactions	26	function definitions	0
global parameters	22	unit definitions	4
rules	12	initial assignments	0

Model Notes

This is the model described in the article:
Vaccination and the dynamics of immune evasion.
Restif O, Grenfell BT. J R Soc Interface. 2007 Feb 22;4(12):143-53. PMID:17210532, doi:10.1098/rsif.2006.0167;
Abstract:
Vaccines exert strong selective pressures on pathogens, favouring the spread of antigenic variants. We propose a simple mathematical model to investigate the dynamics of a novel pathogenic

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strain that emerges in a population where a previous strain is maintained at low endemic level by a vaccine. We compare three methods to assess the ability of the novel strain to invade and persist: algebraic rate of invasion; deterministic dynamics; and stochastic dynamics. These three techniques provide complementary predictions on the fate of the system. In particular, we emphasize the importance of stochastic simulations, which account for the possibility of extinctions of either strain. More specifically, our model suggests that the probability of persistence of an invasive strain (i) can be minimized for intermediate levels of vaccine cross-protection (i.e. immune protection against the novel strain) and (ii) is lower if cross-immunity acts through a reduced infectious period rather than through reduced susceptibility.

This version of the model can be used for both the stochastic and the deterministic simulations described in the article. For deterministic interpretations with infinite population sizes, set the population size N = 1. The model does reproduces the deterministic time course. The initial values are set to the steady state values for a latent infection with strain 1 with an invading infection of strain 2 (I2=1e-06), 100 percent vaccination with a susceptibility reduction =0.7 at birth (p=1), and all other parameters as in figure 3 of the publication.

To be compatible with older software tools, the english letter names instead of the greek symbols were used for parameter names:

parameter	**symbol**	**name**
transmission rate		beta
recovery rate		gamma
birth/death rate		mu
rate of loss of natural immunity		sigma
rate of loss of vaccine immunity	$_{v}$	sigmaV
reduction of susceptibility by primary infection		theta
reduction of infection period by primary infection		nu
reduction of susceptibility by vaccination		tau
reduction of infection period by vaccination		eta

Originally created by libAntimony v1.4 (using libSBML 3.4.1)

2 Unit Definitions

This is an overview of seven unit definitions of which three are predefined by SBML and not mentioned in the model.

2.1 Unit substance

Name individuals

Definition item

2.2 Unit time

Name years

Definition $3.1536 \cdot 10^7$ s

2.3 Unit days

Name days

Definition 86400 s

2.4 Unit per_year

Name per_year

Definition $\left(3.1536 \cdot 10^7 \text{ s}\right)^{-1}$

2.5 Unit volume

Notes Litre is the predefined SBML unit for `volume`.

Definition l

2.6 Unit area

Notes Square metre is the predefined SBML unit for `area` since SBML Level 2 Version 1.

Definition m^2

2.7 Unit length

Notes Metre is the predefined SBML unit for `length` since SBML Level 2 Version 1.

Definition m

3 Compartment

This model contains one compartment.

Table 3: Properties of all compartments.

Id	Name	SBO	Spatial Dimensions	Size	Unit	Constant	Outside
env	environment	0000290	3	1	litre	☑	

3.1 Compartment env

This is a three dimensional compartment with a constant size of one litre.

Name environment

SBO:0000290 physical compartment

4 Species

This model contains eleven species. Section 8 provides further details and the derived rates of change of each species.

Table 4: Properties of each species.

Id	Name	Compartment	Derived Unit	Constant	Boundary Condition
N		env	item	⊟	⊟
S		env	item	⊟	⊟
I1		env	item	⊟	⊟
I2		env	item	⊟	⊟
R1		env	item	⊟	⊟
R2		env	item	⊟	⊟
V		env	item	⊟	⊟
Iv2		env	item	⊟	⊟
J2		env	item	⊟	⊟
J1		env	item	⊟	⊟
R		env	item	⊟	⊟

5 Parameters

This model contains 22 global parameters.

Table 5: Properties of each parameter.

Id	Name	SBO	Value	Unit	Constant
mu		0000022	0.0	$\left(3.1536 \cdot 10^7 \text{ s}\right)^{-1}$	⊟
l_e	life expectancy	0000348	50.0	$3.1536 \cdot 10^7$ s	☑
beta		0000023	0.0	$\left(3.1536 \cdot 10^7 \text{ s}\right)^{-1}$	⊟
R0		0000002	17.0	dimensionless	☑
gamma		0000022	0.0	$\left(3.1536 \cdot 10^7 \text{ s}\right)^{-1}$	⊟
p		0000380	1.0	dimensionless	☑
tau		0000380	0.7	dimensionless	☑
theta		0000380	0.5	dimensionless	☑
nu		0000380	0.5	dimensionless	☑
eta		0000380	0.5	dimensionless	☑
sigma		0000022	0.0	$\left(3.1536 \cdot 10^7 \text{ s}\right)^{-1}$	⊟
sigmaV		0000022	0.0	$\left(3.1536 \cdot 10^7 \text{ s}\right)^{-1}$	⊟
tInf	infectious period (d)	0000348	21.0	86400 s	☑
tImm	immune period (yr)	0000348	20.0	$3.1536 \cdot 10^7$ s	☑
tImm_V	vaccine immune period (yr)	0000348	50.0	$3.1536 \cdot 10^7$ s	☑
strain1_frac		0000360	0.0	dimensionless	⊟
strain2_frac		0000360	0.0	dimensionless	⊟
S_frac		0000360	0.0	dimensionless	⊟
V_frac		0000360	0.0	dimensionless	⊟
R_1_frac		0000360	0.0	dimensionless	⊟
R_2_frac		0000360	0.0	dimensionless	⊟
R_frac		0000360	0.0	dimensionless	⊟

6 Rules

This is an overview of twelve rules.

6.1 Rule mu

Rule mu is an assignment rule for parameter mu:

$$\text{mu} = \frac{1}{\text{l\_e}} \tag{1}$$

6.2 Rule `beta`

Rule `beta` is an assignment rule for parameter `beta`:

$$\text{beta} = \text{R0} \cdot (\text{gamma} + \text{mu}) \tag{2}$$

Derived unit $\left(3.1536 \cdot 10^7 \text{ s}\right)^{-1}$

6.3 Rule `gamma`

Rule `gamma` is an assignment rule for parameter `gamma`:

$$\text{gamma} = \frac{365}{\text{tInf}} \tag{3}$$

6.4 Rule `sigma`

Rule `sigma` is an assignment rule for parameter `sigma`:

$$\text{sigma} = \frac{1}{\text{tImm}} \tag{4}$$

6.5 Rule `sigmaV`

Rule `sigmaV` is an assignment rule for parameter `sigmaV`:

$$\text{sigmaV} = \frac{1}{\text{tImm\_V}} \tag{5}$$

6.6 Rule `strain1_frac`

Rule `strain1_frac` is an assignment rule for parameter `strain1_frac`:

$$\text{strain1\_frac} = \frac{\text{I1} + \text{J1}}{\text{N}} \tag{6}$$

Derived unit dimensionless

6.7 Rule `strain2_frac`

Rule `strain2_frac` is an assignment rule for parameter `strain2_frac`:

$$\text{strain2\_frac} = \frac{\text{I2} + \text{J2} + \text{Iv2}}{\text{N}} \tag{7}$$

Derived unit dimensionless

6.8 Rule S_frac

Rule S_frac is an assignment rule for parameter S_frac:

$$\mathrm{S\_frac} = \frac{\mathrm{S}}{\mathrm{N}} \tag{8}$$

Derived unit dimensionless

6.9 Rule V_frac

Rule V_frac is an assignment rule for parameter V_frac:

$$\mathrm{V\_frac} = \frac{\mathrm{V}}{\mathrm{N}} \tag{9}$$

Derived unit dimensionless

6.10 Rule R_1_frac

Rule R_1_frac is an assignment rule for parameter R_1_frac:

$$\mathrm{R\_1\_frac} = \frac{\mathrm{R1} + \mathrm{R}}{\mathrm{N}} \tag{10}$$

Derived unit dimensionless

6.11 Rule R_2_frac

Rule R_2_frac is an assignment rule for parameter R_2_frac:

$$\mathrm{R\_2\_frac} = \frac{\mathrm{R2} + \mathrm{R}}{\mathrm{N}} \tag{11}$$

Derived unit dimensionless

6.12 Rule R_frac

Rule R_frac is an assignment rule for parameter R_frac:

$$\mathrm{R\_frac} = \frac{\mathrm{R}}{\mathrm{N}} \tag{12}$$

Derived unit dimensionless

7 Reactions

This model contains 26 reactions. All reactions are listed in the following table and are subsequently described in detail. If a reaction is affected by a modifier, the identifier of this species is written above the reaction arrow.

Table 6: Overview of all reactions

№	Id	Name	Reaction Equation	SBO
1	r1	Birth S (unvaccinated)	$\emptyset \xrightarrow{N} S$	0000375
2	r2	Birth V (vaccinated)	$\emptyset \xrightarrow{N} V$	0000375
3	r3	Death in S	$S \longrightarrow \emptyset$	0000375
4	r4	Death in V	$V \longrightarrow \emptyset$	0000375
5	r5	Death in I1	$I1 \longrightarrow \emptyset$	0000375
6	r6	Death in I2	$I2 \longrightarrow \emptyset$	0000375
7	r7	Death in Iv2	$Iv2 \longrightarrow \emptyset$	0000375
8	r8	Death in R1	$R1 \longrightarrow \emptyset$	0000375
9	r9	Death in R2	$R2 \longrightarrow \emptyset$	0000375
10	r10	Death in J1	$J1 \longrightarrow \emptyset$	0000375
11	r11	Death in J2	$J2 \longrightarrow \emptyset$	0000375
12	r12	Death in Rp	$R \longrightarrow \emptyset$	0000375
13	r13	Primary Infection with strain 1	$S \xrightarrow{J1,\ N} I1$	0000375
14	r14	Primary Infection with strain 2	$S \xrightarrow{J2,\ N,\ Iv2} I2$	0000375
15	r15	Primary Infection of V with strain 2	$V \xrightarrow{J2,\ N,\ I2} Iv2$	0000375
16	r16	Recovery (I1)	$I1 \longrightarrow R1$	0000375
17	r17	Recovery (I2)	$I2 \longrightarrow R2$	0000375
18	r18	Secondary Infection with strain 1	$R2 \xrightarrow{N,\ I1} J1$	0000375
19	r19	Secondary Infection with strain 2	$R1 \xrightarrow{N,\ I2,\ Iv2} J2$	0000375
20	r20	Recovery (J1)	$J1 \longrightarrow R$	0000375

№	Id	Name	Reaction Equation	SBO
21	r21	Recovery (J2)	J2 ⟶ R	0000375
22	r22	Recovery (Iv2)	Iv2 ⟶ R	0000375
23	r23	Loss of Immunity (R1)	R1 ⟶ S	0000375
24	r24	Loss of Immunity (R2)	R2 ⟶ S	0000375
25	r25	Loss of Immunity (Rp)	R ⟶ S	0000375
26	r26	Loss of Immunity (V)	V ⟶ S	0000375

7.1 Reaction r1

This is an irreversible reaction of no reactant forming one product influenced by one modifier.

Name Birth S (unvaccinated)

SBO:0000375 process

Reaction equation

$$\emptyset \xrightarrow{\mathrm{N}} \mathrm{S} \tag{13}$$

Modifier

Table 7: Properties of each modifier.

Id	Name	SBO
N		

Product

Table 8: Properties of each product.

Id	Name	SBO
S		

Kinetic Law

Derived unit contains undeclared units

$$v_1 = \mathrm{mu} \cdot (1 - \mathrm{p}) \cdot \mathrm{N} \tag{14}$$

7.2 Reaction r2

This is an irreversible reaction of no reactant forming one product influenced by one modifier.

Name Birth V (vaccinated)

SBO:0000375 process

Reaction equation

$$\emptyset \xrightarrow{\mathrm{N}} \mathrm{V} \tag{15}$$

Modifier

Table 9: Properties of each modifier.

Id	Name	SBO
N		

Product

Table 10: Properties of each product.

Id	Name	SBO
V		

Kinetic Law

Derived unit $\left(3.1536 \cdot 10^{7}\ \mathrm{s}\right)^{-1} \cdot \mathrm{item}$

$$v_2 = \mathrm{mu} \cdot \mathrm{p} \cdot \mathrm{N} \tag{16}$$

7.3 Reaction r3

This is an irreversible reaction of one reactant forming no product.

Name Death in S

SBO:0000375 process

Reaction equation

$$\mathrm{S} \longrightarrow \emptyset \tag{17}$$

Reactant

Table 11: Properties of each reactant.

Id	Name	SBO
S		

Kinetic Law

Derived unit $\left(3.1536 \cdot 10^{7}\ \mathrm{s}\right)^{-1} \cdot \mathrm{item}$

$$v_3 = \mathrm{mu} \cdot \mathrm{S} \tag{18}$$

7.4 Reaction r4

This is an irreversible reaction of one reactant forming no product.

Name Death in V

SBO:0000375 process

Reaction equation

$$\mathrm{V} \longrightarrow \emptyset \tag{19}$$

Reactant

Table 12: Properties of each reactant.

Id	Name	SBO
V		

Kinetic Law

Derived unit $\left(3.1536 \cdot 10^{7}\ \mathrm{s}\right)^{-1} \cdot \mathrm{item}$

$$v_4 = \mathrm{mu} \cdot \mathrm{V} \tag{20}$$

7.5 Reaction r5

This is an irreversible reaction of one reactant forming no product.

Name Death in I1

SBO:0000375 process

Reaction equation

$$\mathrm{I1} \longrightarrow \emptyset \tag{21}$$

Reactant

Table 13: Properties of each reactant.

Id	Name	SBO
I1		

Kinetic Law

Derived unit $\left(3.1536 \cdot 10^{7}\ \mathrm{s}\right)^{-1} \cdot \mathrm{item}$

$$v_5 = \mathrm{mu} \cdot \mathrm{I1} \tag{22}$$

7.6 Reaction r6

This is an irreversible reaction of one reactant forming no product.

Name Death in I2

SBO:0000375 process

Reaction equation

$$\mathrm{I2} \longrightarrow \emptyset \tag{23}$$

Reactant

Table 14: Properties of each reactant.

Id	Name	SBO
I2		

Kinetic Law

Derived unit $\left(3.1536 \cdot 10^{7}\ \mathrm{s}\right)^{-1} \cdot \mathrm{item}$

$$v_6 = \mathrm{mu} \cdot \mathrm{I2} \tag{24}$$

7.7 Reaction r7

This is an irreversible reaction of one reactant forming no product.

Name Death in Iv2

SBO:0000375 process

Reaction equation

$$\mathrm{Iv2} \longrightarrow \emptyset \tag{25}$$

Reactant

Table 15: Properties of each reactant.

Id	Name	SBO
Iv2		

Kinetic Law

Derived unit $\left(3.1536 \cdot 10^7 \text{ s}\right)^{-1} \cdot \text{item}$

$$v_7 = \text{mu} \cdot \text{Iv2} \tag{26}$$

7.8 Reaction r8

This is an irreversible reaction of one reactant forming no product.

Name Death in R1

SBO:0000375 process

Reaction equation

$$\text{R1} \longrightarrow \emptyset \tag{27}$$

Reactant

Table 16: Properties of each reactant.

Id	Name	SBO
R1		

Kinetic Law

Derived unit $\left(3.1536 \cdot 10^7 \text{ s}\right)^{-1} \cdot \text{item}$

$$v_8 = \text{mu} \cdot \text{R1} \tag{28}$$

7.9 Reaction r9

This is an irreversible reaction of one reactant forming no product.

Name Death in R2

SBO:0000375 process

Reaction equation

$$\mathrm{R2} \longrightarrow \emptyset \tag{29}$$

Reactant

Table 17: Properties of each reactant.

Id	Name	SBO
R2		

Kinetic Law

Derived unit $\left(3.1536 \cdot 10^{7}\ \mathrm{s}\right)^{-1} \cdot \mathrm{item}$

$$v_9 = \mathrm{mu} \cdot \mathrm{R2} \tag{30}$$

7.10 Reaction r10

This is an irreversible reaction of one reactant forming no product.

Name Death in J1

SBO:0000375 process

Reaction equation

$$\mathrm{J1} \longrightarrow \emptyset \tag{31}$$

Reactant

Table 18: Properties of each reactant.

Id	Name	SBO
J1		

Kinetic Law

Derived unit $\left(3.1536 \cdot 10^{7}\ \mathrm{s}\right)^{-1} \cdot \mathrm{item}$

$$v_{10} = \mathrm{mu} \cdot \mathrm{J1} \tag{32}$$

7.11 Reaction r11

This is an irreversible reaction of one reactant forming no product.

Name Death in J2

SBO:0000375 process

Reaction equation

$$\mathrm{J2} \longrightarrow \emptyset \tag{33}$$

Reactant

Table 19: Properties of each reactant.

Id	Name	SBO
J2		

Kinetic Law

Derived unit $\left(3.1536 \cdot 10^{7}\ \mathrm{s}\right)^{-1} \cdot \mathrm{item}$

$$v_{11} = \mathrm{mu} \cdot \mathrm{J2} \tag{34}$$

7.12 Reaction r12

This is an irreversible reaction of one reactant forming no product.

Name Death in Rp

SBO:0000375 process

Reaction equation

$$\mathrm{R} \longrightarrow \emptyset \tag{35}$$

Reactant

Table 20: Properties of each reactant.

Id	Name	SBO
R		

Kinetic Law

Derived unit $\left(3.1536 \cdot 10^{7}\ \mathrm{s}\right)^{-1} \cdot \mathrm{item}$

$$v_{12} = \mathrm{mu} \cdot \mathrm{R} \tag{36}$$

7.13 Reaction `r13`

This is an irreversible reaction of one reactant forming one product influenced by two modifiers.

Name Primary Infection with strain 1

SBO:0000375 process

Reaction equation

$$\mathrm{S} \xrightarrow{\mathrm{J1,\ N}} \mathrm{I1} \tag{37}$$

Reactant

Table 21: Properties of each reactant.

Id	Name	SBO
S		

Modifiers

Table 22: Properties of each modifier.

Id	Name	SBO
J1		
N		

Product

Table 23: Properties of each product.

Id	Name	SBO
I1		

Kinetic Law

Derived unit $\left(3.1536 \cdot 10^{7}\ \mathrm{s}\right)^{-1} \cdot \mathrm{item}$

$$v_{13} = \mathrm{beta} \cdot \mathrm{S} \cdot \frac{\mathrm{I1} + \mathrm{J1}}{\mathrm{N}} \tag{38}$$

7.14 Reaction `r14`

This is an irreversible reaction of one reactant forming one product influenced by three modifiers.

Name Primary Infection with strain 2

SBO:0000375 process

Reaction equation

$$\mathrm{S} \xrightarrow{\mathrm{J2,\ N,\ Iv2}} \mathrm{I2} \tag{39}$$

Reactant

Table 24: Properties of each reactant.

Id	Name	SBO
S		

Modifiers

Table 25: Properties of each modifier.

Id	Name	SBO
J2		
N		
Iv2		

Product

Table 26: Properties of each product.

Id	Name	SBO
I2		

Kinetic Law

Derived unit $\left(3.1536 \cdot 10^{7}\ \mathrm{s}\right)^{-1} \cdot \mathrm{item}$

$$v_{14} = \mathrm{beta} \cdot \mathrm{S} \cdot \frac{\mathrm{I2} + \mathrm{J2} + \mathrm{Iv2}}{\mathrm{N}} \tag{40}$$

7.15 Reaction `r15`

This is an irreversible reaction of one reactant forming one product influenced by three modifiers.

Name Primary Infection of V with strain 2

SBO:0000375 process

Reaction equation

$$\mathrm{V} \xrightarrow{\mathrm{J2,\ N,\ I2}} \mathrm{Iv2} \tag{41}$$

Reactant

Table 27: Properties of each reactant.

Id	Name	SBO
V		

Modifiers

Table 28: Properties of each modifier.

Id	Name	SBO
J2		
N		
I2		

Product

Table 29: Properties of each product.

Id	Name	SBO
Iv2		

Kinetic Law

Derived unit contains undeclared units

$$v_{15} = \text{beta} \cdot (1 - \text{tau}) \cdot \text{V} \cdot \frac{\text{I2} + \text{J2} + \text{Iv2}}{\text{N}} \tag{42}$$

7.16 Reaction r16

This is an irreversible reaction of one reactant forming one product.

Name Recovery (I1)

SBO:0000375 process

Reaction equation

$$\text{I1} \longrightarrow \text{R1} \tag{43}$$

Reactant

Table 30: Properties of each reactant.

Id	Name	SBO
I1		

Product

Table 31: Properties of each product.

Id	Name	SBO
R1		

Kinetic Law

Derived unit $\left(3.1536 \cdot 10^7 \text{ s}\right)^{-1} \cdot \text{item}$

$$v_{16} = \text{gamma} \cdot \text{I1} \tag{44}$$

7.17 Reaction r17

This is an irreversible reaction of one reactant forming one product.

Name Recovery (I2)

SBO:0000375 process

Reaction equation

$$\mathrm{I2} \longrightarrow \mathrm{R2} \tag{45}$$

Reactant

Table 32: Properties of each reactant.

Id	Name	SBO
I2		

Product

Table 33: Properties of each product.

Id	Name	SBO
R2		

Kinetic Law

Derived unit $\left(3.1536 \cdot 10^{7}\ \mathrm{s}\right)^{-1} \cdot \mathrm{item}$

$$v_{17} = \mathrm{gamma} \cdot \mathrm{I2} \tag{46}$$

7.18 Reaction r18

This is an irreversible reaction of one reactant forming one product influenced by two modifiers.

Name Secondary Infection with strain 1

SBO:0000375 process

Reaction equation

$$\mathrm{R2} \xrightarrow{\mathrm{N,\ I1}} \mathrm{J1} \tag{47}$$

Reactant

Table 34: Properties of each reactant.

Id	Name	SBO
R2		

Modifiers

Table 35: Properties of each modifier.

Id	Name	SBO
N		
I1		

Product

Table 36: Properties of each product.

Id	Name	SBO
J1		

Kinetic Law

Derived unit contains undeclared units

$$v_{18} = \frac{\text{beta} \cdot (1 - \text{theta}) \cdot \text{R2} \cdot (\text{I1} + \text{J1})}{\text{N}} \tag{48}$$

7.19 Reaction r19

This is an irreversible reaction of one reactant forming one product influenced by three modifiers.

Name Secondary Infection with strain 2

SBO:0000375 process

Reaction equation

$$\text{R1} \xrightarrow{\text{N, I2, Iv2}} \text{J2} \tag{49}$$

Reactant

Table 37: Properties of each reactant.

Id	Name	SBO
R1		

Modifiers

Table 38: Properties of each modifier.

Id	Name	SBO
N		
I2		
Iv2		

Product

Table 39: Properties of each product.

Id	Name	SBO
J2		

Kinetic Law

Derived unit contains undeclared units

$$v_{19} = \frac{\text{beta} \cdot (1 - \text{theta}) \cdot \text{R1} \cdot (\text{I2} + \text{J2} + \text{Iv2})}{\text{N}} \tag{50}$$

7.20 Reaction r20

This is an irreversible reaction of one reactant forming one product.

Name Recovery (J1)

SBO:0000375 process

Reaction equation

$$\text{J1} \longrightarrow \text{R} \tag{51}$$

Reactant

Table 40: Properties of each reactant.

Id	Name	SBO
J1		

Product

Table 41: Properties of each product.

Id	Name	SBO
R		

Kinetic Law

Derived unit contains undeclared units

$$v_{20} = \frac{\text{gamma}}{1 - \text{nu}} \cdot \text{J1} \tag{52}$$

7.21 Reaction r21

This is an irreversible reaction of one reactant forming one product.

Name Recovery (J2)

SBO:0000375 process

Reaction equation

$$\text{J2} \longrightarrow \text{R} \tag{53}$$

Reactant

Table 42: Properties of each reactant.

Id	Name	SBO
J2		

Product

Table 43: Properties of each product.

Id	Name	SBO
R		

Kinetic Law

Derived unit contains undeclared units

$$v_{21} = \frac{\text{gamma}}{1 - \text{nu}} \cdot \text{J2} \tag{54}$$

7.22 Reaction r22

This is an irreversible reaction of one reactant forming one product.

Name Recovery (Iv2)

SBO:0000375 process

Reaction equation

$$\text{Iv2} \longrightarrow \text{R} \tag{55}$$

Reactant

Table 44: Properties of each reactant.

Id	Name	SBO
Iv2		

Product

Table 45: Properties of each product.

Id	Name	SBO
R		

Kinetic Law

Derived unit contains undeclared units

$$v_{22} = \frac{\text{gamma}}{1 - \text{eta}} \cdot \text{Iv2} \tag{56}$$

7.23 Reaction r23

This is an irreversible reaction of one reactant forming one product.

Name Loss of Immunity (R1)

SBO:0000375 process

Reaction equation

$$\mathrm{R1} \longrightarrow \mathrm{S} \tag{57}$$

Reactant

Table 46: Properties of each reactant.

Id	Name	SBO
R1		

Product

Table 47: Properties of each product.

Id	Name	SBO
S		

Kinetic Law

Derived unit $\left(3.1536 \cdot 10^{7}\ \mathrm{s}\right)^{-1} \cdot \mathrm{item}$

$$v_{23} = \mathrm{sigma} \cdot \mathrm{R1} \tag{58}$$

7.24 Reaction r24

This is an irreversible reaction of one reactant forming one product.

Name Loss of Immunity (R2)

SBO:0000375 process

Reaction equation

$$\mathrm{R2} \longrightarrow \mathrm{S} \tag{59}$$

Reactant

Table 48: Properties of each reactant.

Id	Name	SBO
R2		

Product

Table 49: Properties of each product.

Id	Name	SBO
S		

Kinetic Law

Derived unit $\left(3.1536 \cdot 10^7 \text{ s}\right)^{-1} \cdot \text{item}$

$$v_{24} = \text{sigma} \cdot \text{R2} \tag{60}$$

7.25 Reaction r25

This is an irreversible reaction of one reactant forming one product.

Name Loss of Immunity (Rp)

SBO:0000375 process

Reaction equation

$$\text{R} \longrightarrow \text{S} \tag{61}$$

Reactant

Table 50: Properties of each reactant.

Id	Name	SBO
R		

Product

Table 51: Properties of each product.

Id	Name	SBO
S		

Kinetic Law

Derived unit $\left(3.1536 \cdot 10^{7}\ \mathrm{s}\right)^{-1} \cdot \mathrm{item}$

$$v_{25} = \mathrm{sigma} \cdot \mathrm{R} \tag{62}$$

7.26 Reaction r26

This is an irreversible reaction of one reactant forming one product.

Name Loss of Immunity (V)

SBO:0000375 process

Reaction equation

$$\mathrm{V} \longrightarrow \mathrm{S} \tag{63}$$

Reactant

Table 52: Properties of each reactant.

Id	Name	SBO
V		

Product

Table 53: Properties of each product.

Id	Name	SBO
S		

Kinetic Law

Derived unit $\left(3.1536 \cdot 10^{7}\ \mathrm{s}\right)^{-1} \cdot \mathrm{item}$

$$v_{26} = \mathrm{sigmaV} \cdot \mathrm{V} \tag{64}$$

8 Derived Rate Equations

When interpreted as an ordinary differential equation framework, this model implies the following set of equations for the rates of change of each species.

8.1 Species N

SBO:0000240 material entity

Notes total target population size

Initial amount 1 item

This species takes part in seven reactions (as a modifier in r1, r2, r13, r14, r15, r18, r19).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{N} = 0 \tag{65}$$

8.2 Species S

SBO:0000240 material entity

Initial amount 0.0588235 item

This species takes part in eight reactions (as a reactant in r3, r13, r14 and as a product in r1, r23, r24, r25, r26).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{S} = v_1 + v_{23} + v_{24} + v_{25} + v_{26} - v_3 - v_{13} - v_{14} \tag{66}$$

8.3 Species I1

SBO:0000240 material entity

Initial amount 0.00176967 item

This species takes part in four reactions (as a reactant in r5, r16 and as a product in r13 and as a modifier in r18).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{I1} = v_{13} - v_5 - v_{16} \tag{67}$$

8.4 Species I2

SBO:0000240 material entity

Initial amount 10^{-6} item

This species takes part in five reactions (as a reactant in r6, r17 and as a product in r14 and as a modifier in r15, r19).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{I2} = v_{14} - v_6 - v_{17} \tag{68}$$

8.5 Species R1

SBO:0000240 material entity

Initial amount 0.439407 item

This species takes part in four reactions (as a reactant in r8, r19, r23 and as a product in r16).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{R1} = v_{16} - v_8 - v_{19} - v_{23} \tag{69}$$

8.6 Species R2

SBO:0000240 material entity

Initial amount 0 item

This species takes part in four reactions (as a reactant in r9, r18, r24 and as a product in r17).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{R2} = v_{17} - v_9 - v_{18} - v_{24} \tag{70}$$

8.7 Species V

SBO:0000240 material entity

Initial amount 0.9 item

This species takes part in four reactions (as a reactant in r4, r15, r26 and as a product in r2).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{V} = v_2 - v_4 - v_{15} - v_{26} \tag{71}$$

8.8 Species Iv2

SBO:0000240 material entity

Initial amount 0.5 item

This species takes part in five reactions (as a reactant in r7, r22 and as a product in r15 and as a modifier in r14, r19).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{Iv2} = v_{15} - v_7 - v_{22} \tag{72}$$

8.9 Species J2

SBO:0000240 material entity

Initial amount 0 item

This species takes part in five reactions (as a reactant in r11, r21 and as a product in r19 and as a modifier in r14, r15).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{J2} = v_{19} - v_{11} - v_{21} \tag{73}$$

8.10 Species J1

SBO:0000240 material entity

Initial amount 0 item

This species takes part in four reactions (as a reactant in r10, r20 and as a product in r18 and as a modifier in r13).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{J1} = v_{18} - v_{10} - v_{20} \tag{74}$$

8.11 Species R

SBO:0000240 material entity

Initial amount 0 item

This species takes part in five reactions (as a reactant in r12, r25 and as a product in r20, r21, r22).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{R} = v_{20} + v_{21} + v_{22} - v_{12} - v_{25} \tag{75}$$

A Glossary of Systems Biology Ontology Terms

SBO:0000002 quantitative systems description parameter: A numerical value that defines certain characteristics of systems or system functions. It may be part of a calculation, but its value is not determined by the form of the equation itself, and may be arbitrarily assigned

SBO:0000022 forward unimolecular rate constant: Numerical parameter that quantifies the forward velocity of a chemical reaction involving only one reactant. This parameter encompasses all the contributions to the velocity except the quantity of the reactant

SBO:0000023 forward bimolecular rate constant: Numerical parameter that quantifies the forward velocity of a chemical reaction involving two reactants. This parameter encompasses all the contributions to the velocity except the quantity of the reactants.

SBO:0000240 material entity: A real thing that is defined by its physico-chemical structure.

SBO:0000290 physical compartment: Specific location of space, that can be bounded or not. A physical compartment can have 1, 2 or 3 dimensions

SBO:0000348 exponential time constant: Time that it takes for an exponential decay to reach 1/e (about 37%) of the original value. This characterises the frequency response of a first-order, linear time-invariant system. This is also the average lifetime of an element in the decaying set. It is the inverse of the exponential decay constant.

SBO:0000360 quantity of an entity pool: The enumeration of co-localised, identical biochemical entities of a specific state, which constitute a pool. The form of enumeration may be purely numerical, or may be given in relation to another dimension such as length or volume

SBO:0000375 process: A sequential series of actions, motions, or occurrences, such as chemical reactions, that affect one or more entities in a phenomenologically characteristic manner

SBO:0000380 biochemical coefficient: number used as a multiplicative or exponential factor for quantities, expressions or function

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