Modeling the Impact of Vaccination on the Spread of Mpox

Project Module Associated with
2nd Edition, Introduction to Computational Science:
Modeling and Simulation by
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Prerequisite: System Dynamics Modeling

Introduction

For an introduction to Mpox, see (Shiflet 2025).

Parameters

The projects in the module are based on a paper by Omame *et al.* (2025), who developed a system dynamics model for the spread of mpox and the impact of vaccination in high- and low-risk groups on that spread of the disease. High-risk individuals include men who have sex with other men and have at least one of the following characteristics: more than one sexual partner; a partner who has other sexual partners; had a sexually transmitted infection in the past year; or had sex at a sex-on-premises venue. Vaccination can occur before or after exposure within the high-risk group, but vaccination happens only after exposure in some individuals of the low-risk group.

Unlike the scientists' model, we do not consider hospitalizations, so that the compartments and initial values are as in Table 1. We employ the paper's parameters (Table 2), which involve the Canadian population, and their simplifying assumptions, including that there are no births or deaths. Individuals in the high-risk group can have sexual and non-sexual transmission from those infected in the high-risk group but can only have non-sexual transmission from those in the low-risk group. Low-risk individuals only experience non-sexual transmission from those infected in low- and high-risk groups. The chance of transmission is dampened by vaccination.

Table 1. Model compartments, descriptions, and initial value with Canadian population (N_{pop}) of 38,929,902 (Tables 1 and 2, Omame *et al.* 2025)

Compartment	Description	Initial Value
S_{hu}	Susceptible, high-risk, unvaccinated	4% of N_{pop} minus initial E_{hu} (see below)
S_{hv}	Susceptible, high-risk, vaccinated	0
S_l	Susceptible, low-risk, unvaccinated	96% of N_{pop}
E_{hu}	Exposed, high-risk, unvaccinated	10.6

E_{hv}, E_{lv}, E_{lu}	Exposed, high- (h) and low-risk (l), vaccinated (v) and unvaccinated (u)	0
I_{hv}, I_{hu}, I_{lv}, I_{lu}	Infectious, high- (h) and low-risk (l), vaccinated (v) and unvaccinated (u)	0
R_h, R_l	Recovered, high- (h) and low-risk (l)	0

Table 2. Model parameters, descriptions, and values (Table 2, Omame *et al.* 2025)

Variable	Description	Value
t_a	Time when high-risk individuals changed their sexual contact rate because of mpox prevalence	64.1 d
$\beta_s(t)$	Time-dependent mpox sexual transmission constant	If $t \leq t_a$, 1.34216E-07. If $t > t_a$, 2.76137E-08.
β_h	Mpox transmission constant for high-risk non-sexual exposure	1.92654E-10
β_l	Mpox transmission constant for low-risk non-sexual exposure	8.02725E-12
v_h^{pre}	Pre-exposure vaccination rate, high-risk group	0.01023 d^{-1}
v_h^{post}	Post-exposure vaccination rate, high-risk group	0.0045 d^{-1}
v_l^{post}	Post-exposure vaccination rate, low-risk group	0.00225 d^{-1}
ρ	Waning rate of vaccine-induced immunity (i.e., transition rate from S_{hv} to S_{hu})	$\frac{1}{219}$ d^{-1}
ε_v	Effectiveness of vaccine in preventing infection	90%
γ	Recovery rate	$\frac{1}{14}$ d^{-1}
α	Transition rate from exposed to infectious stage	$\frac{1}{8.5}$ d^{-1}
η_v	Scaling parameter for a reduction in mpox transmission for vaccinated individuals	0.15
ω	Waning rate of infection-acquired immunity	$\frac{1}{112}$ d^{-1}
N_{pop}	Population size	38,929,902
N_h	High-risk population size	4% of N_{pop}
N_l	Low-risk population size	96% of N_{pop}

Projects

1. **a.** Develop a system dynamics model using the information from the section "Parameters."

b. Running the model for 180 d, plot the number of cases in the high-risk group verses time. Do a similar plot for the low-risk group. Determine the

maximum number of cases and when it occurs for each group and the peak epidemic size of the total infected population.

2. **a.** Using your model from Project 1a, perform a sensitivity analysis, studying the effect of each of the following parameters on peak epidemic size: β_s, β, v_h^{pre}, v_h^{post}, v_l^{post}, ρ, η_v.

b. To which parameters from Part a is there a positive correlation? Negative correlation? To which parameters is the peak epidemic size most sensitive? Discuss the results and your recommendations for the control of mpox.

3. **a.** In this project, we study the impact of various levels of pre-exposure vaccination in the high-risk group. Running your model from Project 1a for 365 d, on the same graph, plot mpox prevalence (i.e., number of infected individuals) for the high-risk group versus time when no post-exposure vaccination occurs for anyone (i.e., $v_h^{post} = v_l^{post} = 0$) and pre-exposure vaccination (v_h^{pre}) for the high-risk group occurs at 90%, 110%, and 120% of 0.01023 d^{-1}. Determine the peak number of high-risk infected individuals and the cumulative number of cases for each scenario.

b. Repeat Part a for the low-risk group using the same three scenarios.

c. Repeat Part a assuming post-exposure vaccination rates as in Table 2.

d. Repeat Part b assuming post-exposure vaccination rates as in Table 2.

e. Discuss your results and make recommendations.

4. In this project, we examine the impact of post-exposure vaccination on the spread of mpox running your model from Project 1a for 365 d.

a. On the same graph and using $v_h^{pre} = 0.01023$ d^{-1} and $v_l^{post} = 0$, plot the number of infections in the high-risk group for each of the following scenarios: $v_h^{post} = 0$; $v_h^{post} = 0.0045$ d^{-1}; $v_h^{post} = 2 \times 0.0045$ d^{-1}; $v_h^{post} = 3 \times 0.0045$ d^{-1}. Also, for these scenarios, on the same graph, plot the number of infections in the low-risk group. Determine the peak number of infected individuals and the cumulative number of cases in the indicated group and overall for each scenario. Discuss the impact of increasing post-exposure vaccination in the high-risk group on the dynamics of mpox in the population.

b. Consider the impact of post-exposure vaccination in the low-risk group. As in Part a, generate two graphs of the number of infections (for high- and low-risk individuals) using $v_h^{pre} = 0.01023$ d^{-1} for the following scenarios: $v_h^{post} = 0$ and $v_l^{post} = 0$; $v_h^{post} = 0.0045$ d^{-1} and $v_l^{post} = 0.00225$ d^{-1}; $v_h^{post} = 0$ and $v_l^{post} = 0.00225$ d^{-1}; $v_h^{post} = 0.0045$ d^{-1} and $v_l^{post} = 0$. Determine the peak number of infected individuals and the cumulative number of cases in the indicated group and overall for each scenario. Discuss the impact of increasing post-exposure vaccination in the low-risk group on the dynamics of mpox in the population.

c. Using the results from Parts a and b, make recommendations concerning post-exposure vaccination.

5. In this project, we consider vaccination exclusively in the high-risk group (i.e., $v_l^{post} = 0$), running your model from Project 1a for 365 d.

a. Consider the constants previously employed for high-risk vaccination rates pre- and post-exposure, $v_h^{pre*} = 0.01023$ d^{-1} and $v_h^{post*} = 0.0045$ d^{-1}. Generate a graph for the number of infected individuals in the high-risk group for four scenarios: vaccinations at 90% of the current rates (i.e., $v_h^{pre} = 0.90 \times v_h^{pre}$ and $v_h^{post} = 0.90 \times v_h^{post*}$); vaccinations at the current rates; vaccinations increased by 10% of the current rates (i.e., $v_h^{pre} = 1.10 \times v_h^{pre}$ and $v_h^{post} = 1.10 \times v_h^{post*}$); vaccinations increased by 20% of the current rates. At the same time, generate a graph for the number of infected individuals in the low-risk group for the same four scenarios.

b. Discuss the results and make recommendations.

6. In this project, we consider the possibility of an epidemic outbreak of mpox, running your model from Project 1a for two years.

a. Generate two graphs of the number of infected individuals for the high- and low-risk groups when there is no vaccination.

b. Generate two graphs of the number of infected individuals for the high- and low-risk groups when there is only post-exposure vaccination.

c. Discuss the results and indicate if mpox does or does not become eradicated.

References

Omame, Andrew, Sarafa A. Iyaniwura, Adeniyi Ebenezer, Qing Han, Xiaoying Wang, Nicola L. Bragazzi, Jude D. Kong, and Woldegebriel Aseefa Woldegerima. "Pre-exposure vaccination in the high-risk population is crucial in controlling mpox resurgence in Canada." December 2025. *BMC Infectious Diseases* 26(1) DOI:10.1186/s12879-025-12172-y. Accessed Apr. 2, 2026.

Shiflet, George W. 2025. "Emerging Viral Concerns – Mpox (Monkeypox)," *What's News in Science* website. https://wofford-ecs.org/What%27s_News/Mpox/. Accessed Apr. 2, 2026.