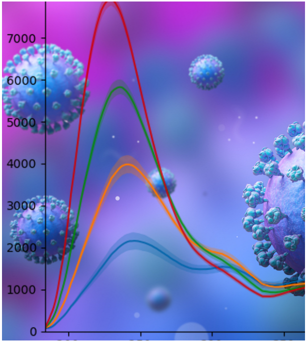
# Vaccination Study Paper and Model M

Roman Neruda, Petra Vidnerová, Gabriela Kadlecová

BEREC, L., LEVÍNSKÝ, R., WEINER, J., ŠMÍD, M., NERUDA, R., VIDNEROVÁ, P., SUCHOPÁROVÁ, G. Importance of vaccine action and availability and epidemic severity for delaying the second vaccine dose. Scientific Reports. 2022, 12(1))

# Contents

- Introduction
  - Vaccination delays dilemma
  - Epidemic models
- Model M
  - Base SEIR model
  - Graph
  - Simulation of interventions
- Vaccination experiments
  - Difference between 21 a 42 days delay
  - Various vaccination effects
- Conclusion



# Vaccination delays dilemma

## Problems

- delays and shortages in vaccine supplies during spring 2021
- limited number of individuals vaccinated

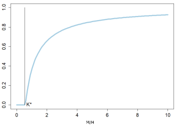
## Strategy

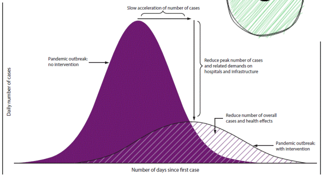
- delay the second dose for a longer period than originally recommended (21 to 42 days)

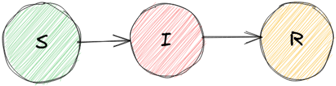
## Questions

- does the strategy pay off?
- under what conditions

# Epidemiological models




## Model types

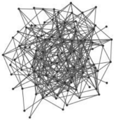
- compartmental models - susceptible, infected, recovered groups
- agent based models - work on individual level

## Vaccination Study

- three different models:
  - deterministic compartmental model (model H)
  - stochastic discrete-time SEIR model (model F)
  - agent-based model (model M)

# From Compartments to Agents


- Compartment models have difficulties in modelling non-pharmaceutical interventions (contact reductions, partial closures)



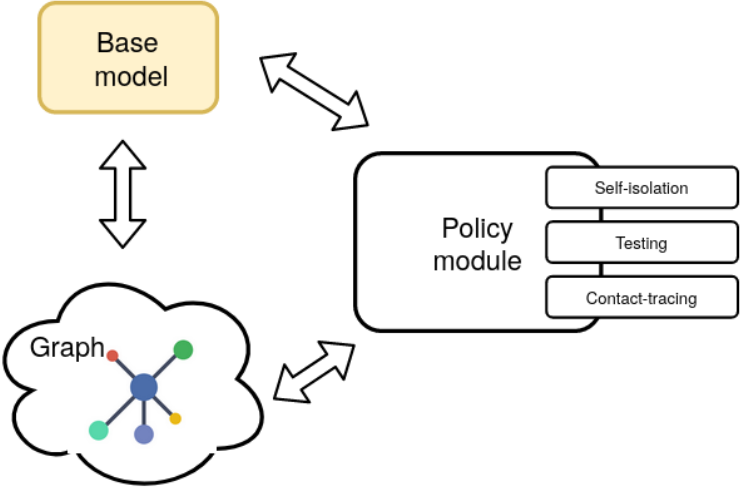
- Agent models work with a population of individuals
- Agents are connected in a network, i.e. a contact graph

- Agents provide simulation tools for modelling of individual human parameters (age, etc.) and behaviour
- Enable detailed simulation of various interventions

# Model M

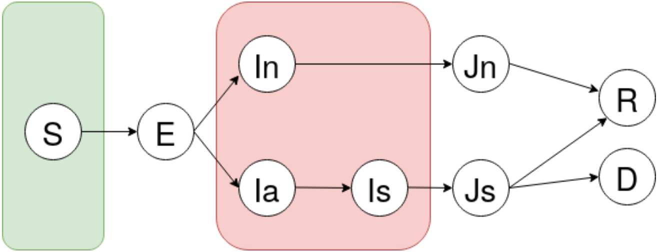

- Agent based model
- Why M? M refers to the world “town” (in Czech “město”)
- Works with a population of individuals (56 000 nodes/agents)
- Uses a realistic contact graph
- The graph models one Czech county
- Focus on comparing interventions (rather than on precise forecasting)
- Enables modelling of non-pharmaceutical interventions
- Simulates quarantines, isolation, flat closures on individual level

# Model M


Base
model
Policy
module
Self-isolation
Testing
Contact-tracing
Graph

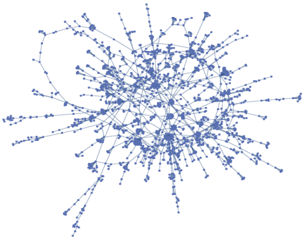
# Base model - SEIR model

- Each individual is in exactly one of possible states
- Iterates on a daily basis
- Transition $S \rightarrow E$ is given by $\beta$ (infectiousness) and the contact graph
- Other transitions depends on parameters of the infection only



# Model M - graph

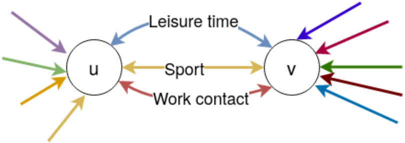
- Realistic graph
- Model of a real Czech county (Hodonín)
- Models contacts between people
- Multi-graph



- Data sources:
  - Czech Statistical Office
  - State Administration of Land Surveying and Cadastre
  - Ministry of Education, Youth and Sports
  - PAQ research, Median
  - Openstreet map
  - Expert knowledge
- Modified Barabasi-Albert algorithm
- Prem contact matrices

# Model M - graph

- Multi-graph, organised in layers (family, work, school, etc.)
- 56 thousands nodes
- 2.8 millions edges
- 30 layers

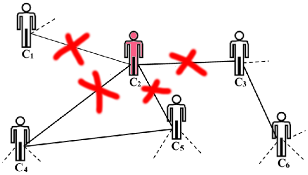



- Edge parameters: contact probability $p$, intensity $i$, layer type $l$
- Each day an edge is activated with the probability $w_l * p$
- Probability of infection transmission

$$p_{S\to E}(e) = \begin{cases} \beta * i & \text{if the edge is active} \\ 0 & \text{otherwise} \end{cases}$$

# Model M - policy module

- Implements various interventions and changes in people's behaviour
- Invoked on daily basis
- Modifies the graph
- Controls and changes model parameters




## Interventions

- Protective measures - reduction of $\beta$
- Flat contact restrictions - switching off whole layers
- Individual isolation
  - Testing, isolation, contact tracing

# Vaccination policy

## Vaccination in model

- non-detected individuals vaccinated in stochastic manner
- vaccination according to the given scenario (age group, etc.)
- counter of number of days from vaccination
- vaccine efficacy $v_e^1$ (after first dose), $v_e^2$ (after the second dose)

## Vaccination effect

- Infection: reduce chance of infection upon contact with and infectious person
- Symptoms: if infected, reduced probability of symptoms appearance
- Infection & symptoms

# Experiments with vaccination

## Calibration

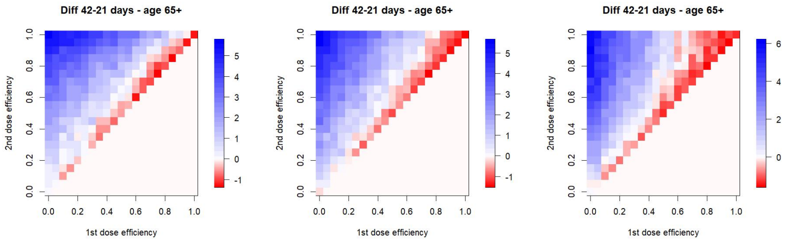
- models calibrated on the past data
- model M calibrated on data from October 5, 2020 until February 17, 2021

## Experiment

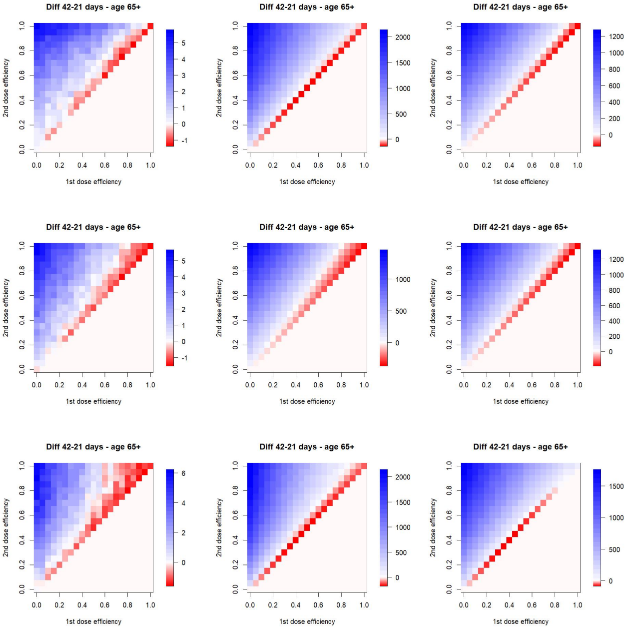
- Various efficacy of vaccination
- Various effects of vaccination
- Comparing different scenarios of second dose delay - 21 a 42 days
- Difference in number of deaths till June 30

# Different vaccination effects

- Infection effect (left), Symptoms effect (middle), Both (right)

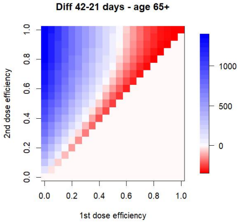


# Different vaccination effects - three models



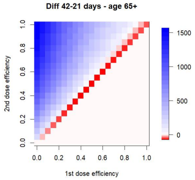
# Effect on hospitalisations, ICU need and death probability

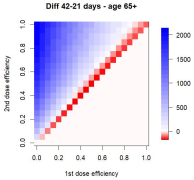
- 42 days delay most advantageous when vaccine effects hospitalisation and ICU need and probability of death

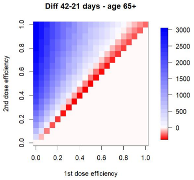


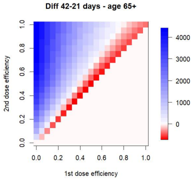
# Different epidemic severity

- contact level 35%, 45%, 55%, 65%
- the more severe epidemic, the more advantageous the longer delay



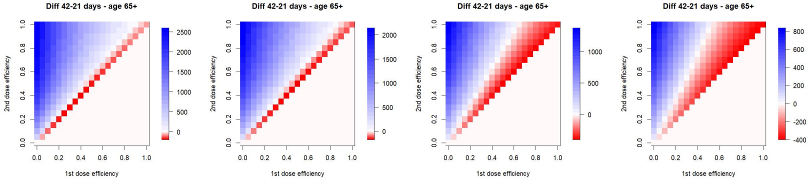



# Different vaccine availability

- vaccines available twice more, like reality, twice less, four times less
- with less availability the 42 delay more advantageous



# Conclusion

## Results

- vaccine action preventing infections and symptoms appearance, mild epidemic, sufficient vaccine supply $\rightarrow$ 21 days delay
- vaccine action preventing severe symptoms and death, severe epidemic, low vaccine supply $\rightarrow$ 42 days delay

## Model M Summary

- Agent based epidemic model with a realistic graph
- Enables simulation of various interventions on individual level
- Modular and extensible (different graphs, vaccination, etc.)

# THANK YOU! QUESTIONS?

## Resources

- Berec et al. Importance of vaccine action and availability and epidemic severity for delaying the second vaccine dose, Scientific Reports volume 12, Article number: 7638 (2022)
- Berec et al. On the Contact Tracing for COVID-19: A simulation study.
- Monografie v českém jazyce: Rok s pandemií covid-19 (Reflexe v poločase), Karolinum, 2023
- Software github.com/epicity-cz/model-m