Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Lecture with Computer Exercises:
Modelling and Simulating Social Systems

Project Report

Pertussis resurgence in societies with high vaccination coverage

Hannah Niese, Markus Niese & Timo Schönegg

Zurich
Dec 2018

Agreement for free-download

We hereby agree to make our source code for this project freely available for download from the web pages of COSS. Furthermore, we assure that all source code is written by ourselves and is not violating any copyright restrictions.

Hannah Niese | Markus Niese | Timo Schönegg

Contents

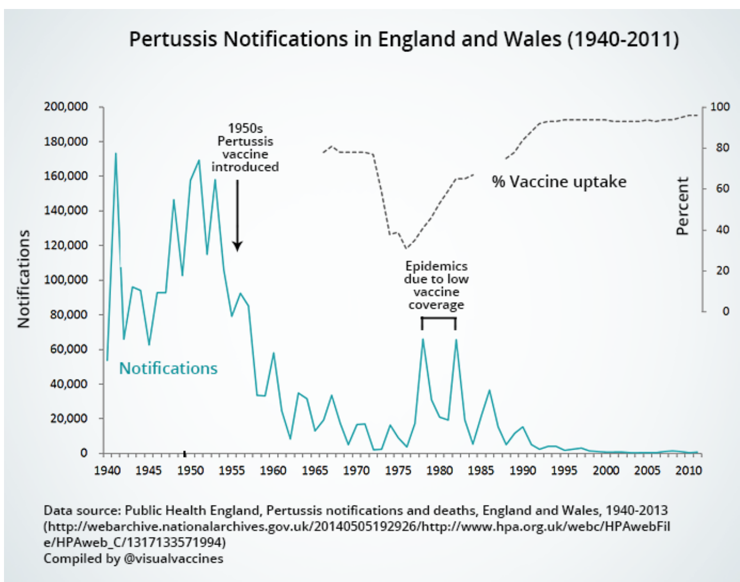
1 Abstract

2 Individual contributions

3 Introduction and Motivations

Vaccines are without doubt one of the greatest advances in medicine, whose widespread use has lead to the eradication or restriction of some of the deadliest diseases, including smallpox, polio and measles. Every vaccination carries a small risk of side effects. According to the WHO, severe adverse events are extremely rare for most vaccines (for the Hepatitis B vaccine only one in a million is affected) or not yet clinically proven like in the case of Hepatitis A.[1] However, contested medical papers and rumours have led to a reluctance to vaccinate in parts of the society.

We modelled the specific case of Pertussis or Whooping cough, as there have been several incidents where a rising number of infections have been observed despite relatively high vaccination rates. One of these cases is the Netherlands, where, despite a coverage rate of 95% several cases of Pertussis have been registered. Even though these cases might be few, the survival of the disease means that the coverage rate should remain high.



[1] WHO (2018-10-06), $http://www.who.int/vaccine_safety/initiative/tools/vaccinfosheets/en/$

4 Description of the Model

4.1 SIR Model

We used an SIR model for the simulation of the spreading of Pertussis. Pertussis is transmitted by respiratory droplets human-to-human with an incubation period ranging from 9 to 14 days, while symptoms can last up to 6 weeks. [2]

```
prob_for_diseases = 0.001
#probability of infection from outside sources
prob_for_contact_infection = 0.5
```

This estimation is taken from a simulation which assesses the susceptibility of family members. We assume that a person has frequent contact with close family members and modulate the outcome with another variable that uses the probability that you meet with someone from your network on a given day to depict a realistic depiction of the society. [3]

4.1.1 Modelling immunisation

As the protection of the vaccination wanes after time, we decided to forego including a function to renew the population (births, deaths) as Pertussis is not a disease that frequenly causes death. To simplify the length of the protection acquired either by being vaccinated or by having recovered from Pertussis, we take a period of 13 years with a standard deviation of 2 years, which is on the conservative side, given that only 10% of those vaccinated are still protected 12 years after the vaccination. There is less data available to assess the immunity after having recovered from the disease, but it can be assumed to be similar to the immunity acquired by vaccination. In addition we analyse a society with a high rate of coverage, so that the majority will have acquired their immunity by vaccination.

4.2 Vaccination Decision

We assume that every person is a rational decision maker, who decides whether or not to get vaccinated based on the perceived costs of getting vaccination vs risking getting sick. We assume that the vaccination provides 100% safety, equal to having recovered from the disease. However, as recent research has shown that the protection

[2] Torres Codeço, C; Mendes Luz, P; Is pertussis actually reemerging? Insights from an individual-based model, Cad. Saúde Pública vol.17 no.3 Rio de Janeiro May/June 2001

[3] Estimation of Household Transmission Rates of Pertussis and the Effect of Cocooning Vaccination Strategies on Infant Pertussis Epidemiology23(6):852-860, November 2012

considerably decreases about 10 to 40 years after the initial protection (vaccination or recovery). [4] To include this in our model without further complicating it, we modelled that the protection stops 12 years after the last immunisation,

has an initial inclination to vaccinate themselves, which we initialise before the simulation.

4.3 Cost functions

To evaluate the probability of a person to get vaccinated, we use a static model in which each individual assesses their personal cost of getting vaccinated versus getting infected.

4.3.1 Perceived vaccination cost

4.3.2 Perceived infection cost

The perceived vaccination cost of a person changes in two scenarios:

1. When someone in the immediate surroundings is infected, the perceived infection cost rises by a factor of 1.2 (after recovery of the contact it decreases by 0.9).
2. When the global level of

4.4 Equilibria for two people

In the case of two people

4.5 Equilibria for N people

4.6 Important Parameters

First we look at the dynamics of the disease. Pertussis is highly contagious, and is transmitted via the respiratory organs. Sneezing, coughing or even speaking can release enough infected particles to cause the disease, making crowded spaces such as public transport and educational institutions ideal for transmission. We therefore initialised everyone in the network to have 40 connections, of which he or she meets 40% every day, which seems realistic given that even a short encounter on a train station might cause the disease.

```
#Random probability (per day and person) to become sick
#without being infected by someone else
prob_for_diseases = 0.00003
```

[4] INSERT RESEACH ABOUT 12 YEARS HERE

```
#probability to infect someone when there is contact
prob_for_contact_infection = 0.5

#incubation time (in days)
incubation_time = 10

#days from infection, after this time a person is recovered
time_to_get_healthy = 10
```

The patient starts being infectious 7 days after infection, and remains so until they recover [5]

5 Implementation

The model was implemented using Python. First, we wrote the basic SIR model with infection and recovery. Then we added the "vaccination function" which returns whether a person is getting vaccinated or not. Finally,

5.1 SIR Model Implementation

6 Simulation Results and Discussion

6.1 Limitations

6.2 Algorithm Performance

7 Summary and Outlook

8 References

Table of References:

Bauch, C. T., & Earn, D. J. (2004). Vaccination and the theory of games. Proceedings of the National Academy of Sciences, 101(36), 13391-13394.

[5] Bundeszentrale für Gesundheitliche Aufklärung Germany, Keuchhusten *www.infektionsschutz.de/erregersteckbriefe/keuchhusten/#c3580*, accessed 30.11.2018

Eshel, I. (1996). On the changing concept of evolutionary population stability as a reflection of a changing point of view in the quantitative theory of evolution. Journal of mathematical biology, 34(5-6), 485-510.

Heal, G., & Kunreuther, H. (2005). The vaccination game. Risk Management and Decision Processes Center Working Paper, (05-10).

Estimation of Household Transmission Rates of Pertussis and the Effect of Cocooning Vaccination Strategies on Infant Pertussis Epidemiology23(6):852-860, November 2012

Torres Codeço, C; Mendes Luz, P; Is pertussis actually reemerging? Insights from an individual-based model, Cad. Saúde Pública vol.17 no.3 Rio de Janeiro May/June 2001

$https://ourworldindata.org/vaccination$

$https://www.gapminder.org/data/$ search for 'vaccine'

Immunization coverage, system indicators and schedule, and disease incidence $www.who.int/immunization/monitoring_surveillance/data/en$