



Eidgenössische Technische Hochschule Zürich  
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# Lecture with Computer Exercises: Modelling and Simulating Social Systems

Project Report

**Pertussis resurgence in societies  
with high vaccination coverage**

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## **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.

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## 1 Abstract

## 2 Individual contributions

## 3 Introduction and Motivations

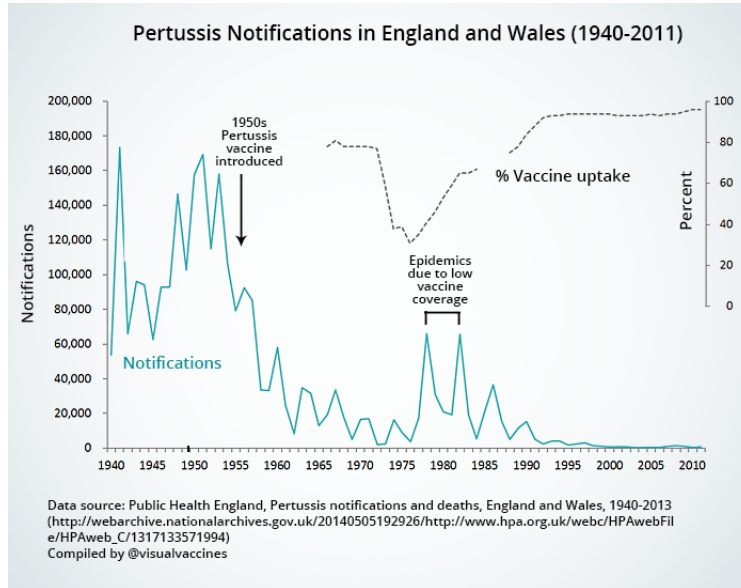
Vaccines are without doubt one of the greatest advances in medicine, whose widespread use has led to the eradication or restriction of some of the deadliest diseases, including smallpox, polio and measles. Every vaccination carries a small risk of side effects. According to the WHO, severe adverse events 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.<sup>1</sup> 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. One of the reasons is waning immunisation and the lack of people getting vaccinated. Even though these cases might be few, the survival of the disease means that the coverage rate should remain high.

This paper tries to answer the question of how people take decisions on whether to get vaccinated or not, and how the dynamics of the disease changes.

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<sup>1</sup>WHO (2018-10-06), [http : //www.who.int/vaccine\\_safety/initiative/tools/vaccinfosheets/en/](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. <sup>2</sup>

```
#probability of infection from outside sources
prob_for_diseases = 0.001
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. <sup>3</sup>

Markus

<sup>2</sup>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

<sup>3</sup>Estimation of Household Transmission Rates of Pertussis and the Effect of Cocooning Vaccination Strategies on Infant Pertussis Epidemiology 23(6):852-860, November 2012

In our model individuals have the choice of vaccinating or not. They do that based on the current benefits of each option. The main parameters influencing their decision are the perceived risk of side effects of the vaccination  $r_v$  and perceived risk to get harmed by the disease  $r_i$ . These two parameters do not just have to be caused by one specific reason but can be composed of a number of factors. Certainly the actual risks play a part, but equally the perceived risk, which will rise for example when individuals in the neighborhood are infected. But also financial consideration may play a part. We will elaborate on the possible influences in Chapter. . . . Furthermore we will assume that the disease can only be transmitted by humans. Childhood diseases like pertussis or measles are of that kind. Diseases like Cholera or Malaria can also infect someone if nobody else is infected. This sort of diseases will not be looked at in our initial model. We will however incorporate that possibility later. The probability to get infected  $PI_i$  is primarily determined by the proportion of people that are currently infected  $li$  and the proportion of people that are vaccinated  $l_c$

#### 4.1.1 Modelling immunisation

We assume that the vaccination provides 100% safety, equal to having recovered from the disease. However, as recent research has shown that the protection considerably decreases about 10 years after the initial protection. 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.<sup>4</sup> As this dynamics of waning immunity already provides us with a constant population, we do not model births and deaths, as Pertussis is not a disease that frequently causes death.

## 4.2 Network

### 4.3 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.<sup>5</sup>

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<sup>4</sup>Wendelboe, Van, Salmaso, Englund: Duration of immunity against pertussis after natural infection or vaccination. S58–S61

<sup>5</sup>INSERT RESEACH ABOUT 12 YEARS HERE

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

**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 One person among N people

To illustrate this, let us have a look how a person A takes the decision to vaccinate: We initialise each person with a value for perceived vaccination cost and perceived infection cost (which are the same for everyone at the beginning. If a person B in the network of A falls ill, A's perceived infection cost rises by a factor of 1.2. If another person C in A's network were to fall ill, A's perceived infection cost would rise by a factor of 1.2 again. After person B recovers, A's perceived infection cost are multiplied by a factor of 0.9, the same is true when person C recovers, leaving person A with a perceived risk of infection of 1.1664 compared to 1 at the beginning, accounting for the fact that the person is more aware of the cost of the disease because B and C in their network have been affected.

### 4.5 Equilibria for N people

In addition to the "local" information of the nodes in the network of the person, there is also information on the general coverage and infection level in society available to the individual, as well as an additional factor that we call

`change_infection_cost_population`

```
def change_infection_cost_population(people_list, factor, probability):  
    """ Change the percieved_infec_cost by a factor for every Person  
    with some probability
```

Args:

```

    people_list (list of Person):
    The list of people whose parameter should be changed
    factor (float):
    The factor by which the percieved_infec_cost should be changed
    probability (float , between 0 and 1):
    probability of each person to get the percieved_infec_cost changed

Returns:
    people_list (list of Person):
    The list of people whose parameter have been changed
"""

```

## 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

```

```

#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 <sup>6</sup>

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<sup>6</sup>Bundeszentrale für Gesundheitliche Aufklärung Germany, Keuchhusten [www.infektionsschutz.de/erregersteckbriefe/keuchhusten/#c3580](http://www.infektionsschutz.de/erregersteckbriefe/keuchhusten/#c3580), accessed 30.11.2018



## 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:

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*[https : //ourworldindata.org/vaccination](https://ourworldindata.org/vaccination)*

*[https : //www.gapminder.org/data/](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](http://www.who.int/immunization/monitoring_surveillance/data/en)*