Modelling in Public Health

SE Scientific Communication
Summer 2019

Lukas Richter

28. June 2019

Content

Background

Public Health is "[. . .] the science and art of preventing disease, prolonging life and promoting human health [. . .]." – Charles-Edward Amory Winslow

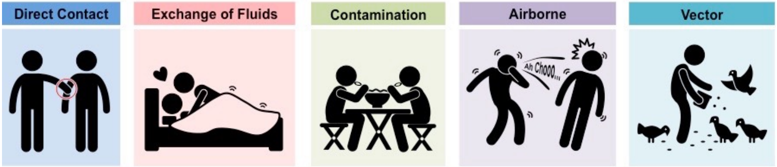
Infectious diseases are a serious **burden** for human health

Loss of QUALYs and also money

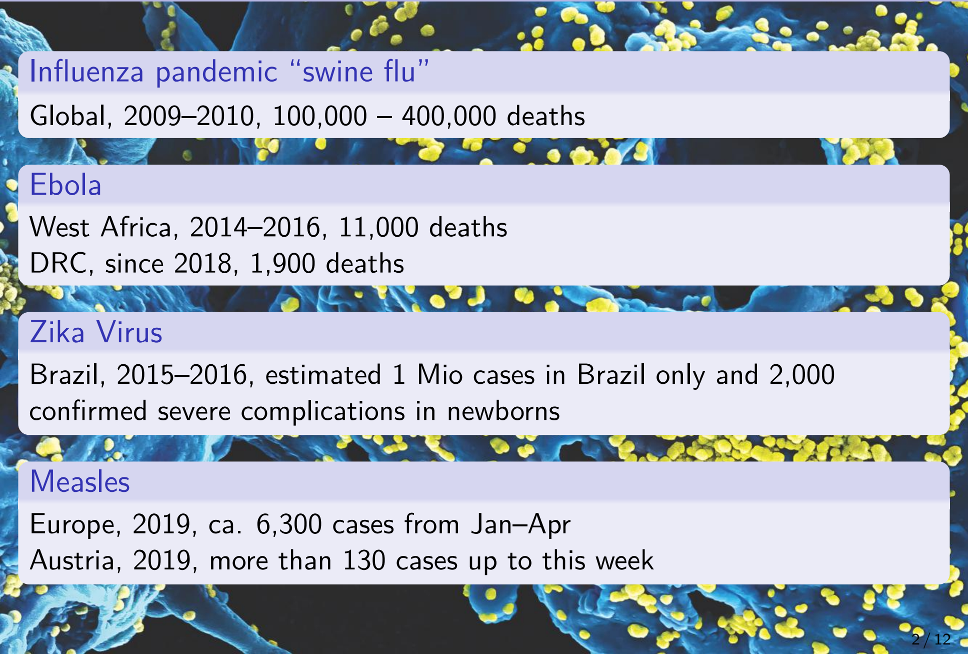
WHO: **50,000 deaths per day** due to infectious diseases

Outbreaks vs endemic infection

Different chains of **transmission**:



Outbreaks



Influenza pandemic “swine flu”

Global, 2009–2010, 100,000 – 400,000 deaths

Ebola

West Africa, 2014–2016, 11,000 deaths
DRC, since 2018, 1,900 deaths

Zika Virus

Brazil, 2015–2016, estimated 1 Mio cases in Brazil only and 2,000 confirmed severe complications in newborns

Measles

Europe, 2019, ca. 6,300 cases from Jan–Apr
Austria, 2019, more than 130 cases up to this week

How can modellers help?

Outbreak situations:

Exploit all available data

Inform response team in real time

Prioritise interventions

Non outbreak situations:

Evaluate health programmes (vaccination, WHO elimination targets)

Find **high impact and cost-effective** interventions

Allow **evidence** based decisions

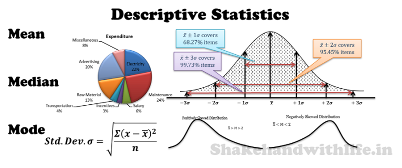
Benefits of modelling:

Low cost! Clinical trials are expensive and seldom large enough

Often little or no data to analyse (new emerging diseases)

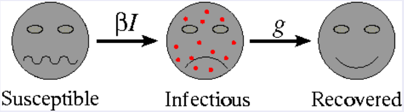
Types of models

Statistical



- Descriptive
- Regression
- Bayesian statistics
- Spatial models

Mathematical



- Dynamic, compartmental (SIR)
- Stochastic - Markov chain
- Deterministic
- Agent-based

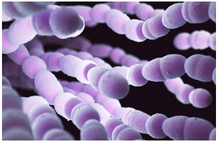
Intervention effect – Invasive Pneumococcal Disease (IPD)

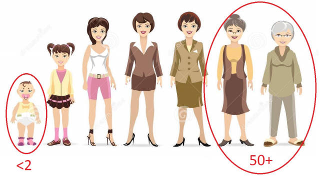
Caused by ***Streptococcus pneumoniae***

90 distinct pneumococcal serotypes

Highest burden: **infants** and **elderly**

Vaccine introduced in 2012 in AT for children





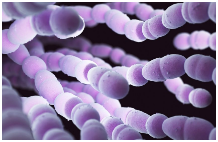
Intervention effect – Invasive Pneumococcal Disease (IPD)

Caused by ***Streptococcus pneumoniae***

90 distinct pneumococcal serotypes

Highest burden: **infants** and **elderly**

Vaccine introduced in 2012 in AT for children



Vaccine effect? Direct? Indirect (elderly)?

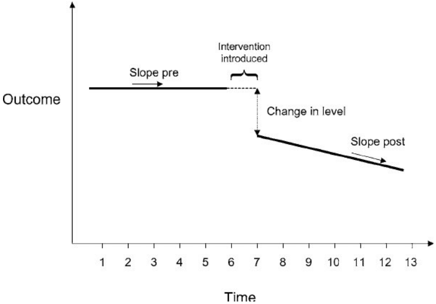
IPD – A Segmented Regression Model

Serfling-like Model

$$\begin{aligned}\log(Y_t) &= \beta_0 + \beta_1\, t + \beta_2 \sin\left(\frac{2\pi t}{12}\right) + \beta_3 \cos\left(\frac{2\pi t}{12}\right) \\ &\quad + \beta_5\,(t - t_0)^+ + \mathbb{1}_{t-t_0>0}\left[\beta_4 + \beta_6 \sin\left(\frac{2\pi t}{12}\right) + \beta_7 \cos\left(\frac{2\pi t}{12}\right)\right] \\ &\quad + \log(pop_t)\end{aligned}$$

with

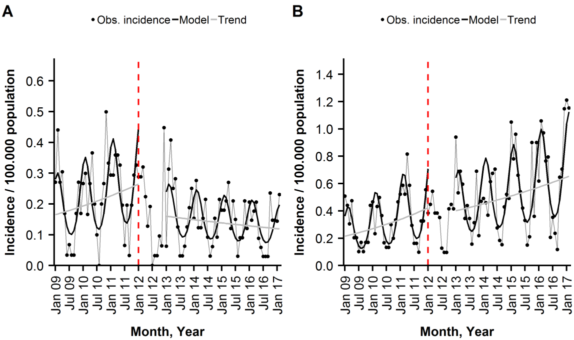
$$(x)^+ = \begin{cases} x, & \text{if } x > 0, \\ 0, & \text{otherwise.}\end{cases}$$



Richter et al., 2019

IPD – Results

Figure: Monthly incidence of (A) **vaccine type** IPD (B) **non vaccine type** IPD, among the ≥**50 years old**, observed and modelled, Austria



The vaccine type IPD was **reduced by 67%** (95% CI: 32%; 84%).

Richter et al., 2019

Mathematical modelling – Zika Virus

Humans infected by **mosquitos**

daytime-active *Aedes* family

Latin American Zika epidemic (Feb 2016)

Summer Olympics in Rio

Global transmission (75 countries)

e.g. *A. albopictus* **found in AT** in 2012

Mostly **flu-like** or **no** symptoms

Dangerous for **foetuses and neonates**

Brain malformations

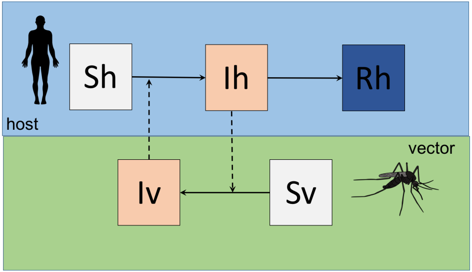
Microcephaly (small head)

Figure: *Aedes aegypti*

Source: Muhammad Mahdi Karim, Wikipedia

Transmission model of Zika Virus

Vars	Description
S_h	Susceptible Humans
I_h	Infected/Infectious humans
R_h	Humans recovered from infection (with lifelong immunity)
S_v	Susceptible vectors
E_v	Exposed vectors



adapted from
https://www.reconlearn.org/ and Ferguson et al., 2016

Transmission model of Zika Virus

Humans/Host

$$\frac{dS_h}{dt} = \mu_h N_h - \frac{\beta_h b}{N_h} S_h I_v - \mu_h S_h$$

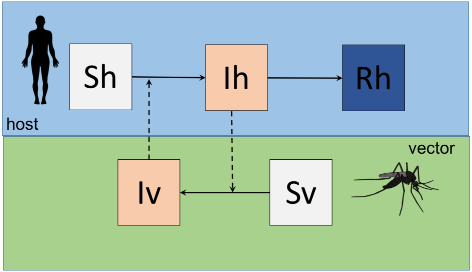
$$\frac{dI_h}{dt} = \frac{\beta_h b}{N_h} S_h I_v - (\gamma_h + \mu_h) I_h$$

$$\frac{dR_h}{dt} = \gamma_h I_h - \mu_h I_h$$

Vectors

$$\frac{dS_v}{dt} = \mu_v N_v - \frac{\beta_v b}{N_h} I_h S_v - \mu_v S_v$$

$$\frac{dI_v}{dt} = \frac{\beta_v b}{N_h} I_h S_v - \mu_v I_v$$



adapted from
`https://www.reconlearn.org/` and Ferguson et al., 2016

Zika Virus - Modelling Outcome

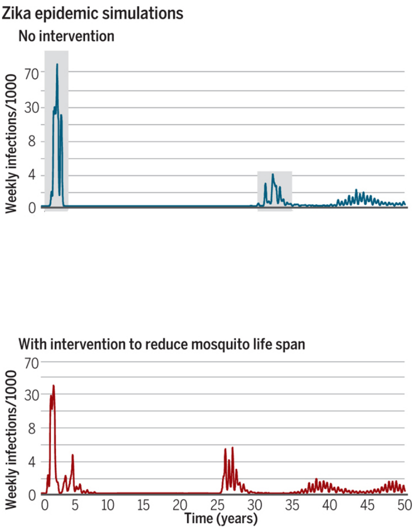
Herd immunity after first epidemic

Epidemic will **re-occur** every 15-20 yrs

An epidemic will last about 3-5 yrs

Shorter on local scale: 6 months

Develop **new interventions** before new large-scale outbreaks occur



Ferguson et al., 2016

Conclusion

Modelling **increasingly important**

Guide the highest **impact** and **cost-effective** preventions

Critical tool for public health action

Model limitations

Decision makers **benefit** - so does the population

Challenges need to be solved

شكراً جزيلاً

thank you
danke
謝謝
ngiyabonga
teşekkür ederim
gracias
спасибо
merci
obrigado
dziękuję
bedankt
sukriya
kop khun krap
go raibh maith agat
mochchakkeram
arigatô
dakujem
terima kasih
grazie
감사합니다
мерси
tapadh leat
dank je
hvala
sagolun
takk
ευχαριστώ
Баярлалаа
рахмат
хвала
ありがとう

Any questions?

References

[1] Craig R. Ramsay et al. "Interrupted Time Series Designs in Health Technology Assessment: Lessons from Two Systematic Reviews of Behavior Change Strategies". In: *International Journal of Technology Assessment in Health Care* 19.4 (2003), pp. 613–623. ISSN: 0266-4623. pmid: 15095767.

[2] Lukas Richter et al. "Invasive Pneumococcal Diseases in Children and Adults before and after Introduction of the 10-Valent Pneumococcal Conjugate Vaccine into the Austrian National Immunization Program". In: *PloS One* 14.1 (2019), e0210081. ISSN: 1932-6203. DOI: 10.1371/journal.pone.0210081. pmid: 30629620.

[3] Neil M. Ferguson et al. "Countering the Zika Epidemic in Latin America". In: *Science* 353.6297 (July 22, 2016), pp. 353–354. ISSN: 0036-8075, 1095-9203. DOI: 10.1126/science.aag0219. pmid: 27417493. URL: https://science.sciencemag.org/content/353/6297/353 (visited on 06/19/2019).

[4] J. Nielsen et al. "European All-Cause Excess and Influenza-Attributable Mortality in the 2017/18 Season: Should the Burden of Influenza B Be Reconsidered?" In: *Clinical Microbiology and Infection* (Feb. 18, 2019). ISSN: 1198-743X. DOI: 10.1016/j.cmi.2019.02.011. URL: http://www.sciencedirect.com/science/article/pii/S1198743X19300588 (visited on 04/08/2019).

[5] Polonsky Jonathan A. et al. "Outbreak Analytics: A Developing Data Science for Informing the Response to Emerging Pathogens". In: *Philosophical Transactions of the Royal Society B: Biological Sciences* 374.1776 (July 8, 2019), p. 20180276. DOI: 10.1098/rstb.2018.0276. URL: https://royalsocietypublishing.org/doi/10.1098/rstb.2018.0276 (visited on 06/18/2019).

[6] R. E. Serfling, I. L. Sherman, and W. J. Houseworth. "Excess Pneumonia-Influenza Mortality by Age and Sex in Three Major Influenza A2 Epidemics, United States, 1957-58, 1960 and 1963". In: *American Journal of Epidemiology* 86.2 (Sept. 1967), pp. 433–441. ISSN: 0002-9262. DOI: 10.1093/oxfordjournals.aje.a120753. pmid: 6058395.

[7] C. J. E. Metcalf, W. J. Edmunds, and J. Lessler. "Six Challenges in Modelling for Public Health Policy". In: *Epidemics*. Challenges in Modelling Infectious DIsease Dynamics 10 (Mar. 1, 2015), pp. 93–96. ISSN: 1755-4365. DOI: 10.1016/j.epidem.2014.08.008. URL: http://www.sciencedirect.com/science/article/pii/S1755436514000620 (visited on 06/23/2019).